SYLVAN LAKE, INDIANA

A FINAL FEASIBILITY REPORT

SUBMITTED TO

SYLVAN LAKE IMPROVEMENT ASSOCIATION, INC.

BY

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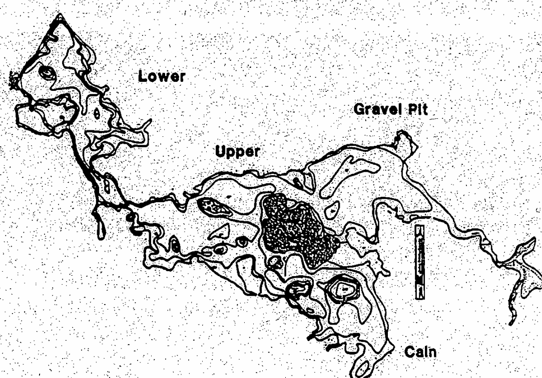

MAY 1990

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Turnbell Engineering Co. of Fort Wayne, Indiana was responsible for all collection of limnological data for 1988. The author was responsible for completion of a final lake enhancement report based on these data as well as any historical data available in the files of federal, state, and local agencies and universities. The author was not responsible for any aspect of the study design for Turnbell Engineering.

EXECUTIVE SUMMARY

Sylvan Lake is a eutrophic lake in Noble County composed of four interconnected basins. Water quality began to deteriorate early in this century associated with untreated sewage from the town of Kendallville so that by the 1930's management problems were apparent for algal and macrophytes and the gamefish population was being altered. The lake has been the subject of several management investigations including a series of winter drawdowns during the 1970's and a fish eradication program in 1984. The most dramatic improvement in water quality occured as a result of the latter, and macrophytes have begun to recolonize the lake after a prolonged period of near total absence.

The principal contributing factors for the eutrophication of Sylvan Lake has been sewage from the town of Kendallville and runoff from agricultural areas of the watershed. Together, these factors contribute an estimated 59% of total phosphorus loading annually to Sylvan Lake.

It is recommended that in-lake management techniques will not be extremely effective until watershed phosphorus is reduced substantially. In particular, it is recommended that the wetland at the eastern end of Gravel Pit Basin be expanded in order to serve as a nutrient trap for the principal streams entering the lake. Additional sites for wetland construction should be found on Henderson Lake Ditch to trap nutrients from the town of Kendallville. Finally, any future management plan for Sylvan Lake and its watershed must consider restoration of Henderson Lake as a necessity. This lake receives the sewage from Kendallville, has become increasingly infilled in recent years, and will act as a significant nutrient loader to Sylvan Lake for decades via sediment release of phosphorus even if the nutrient loading from Kendallville is totally eliminated.

INTRODUCTION

Sylvan Lake, Noble County, is composed of four basins from east to west: Gravel Pit, Cain, Upper, and Lower (Figure 1). The present lake was created in 1839 as a feeder reservoir for the proposed Michigan and Erie Canal that was to run from Michigan City to Fort Wayne. The dam acted to join together the four basins that previously were separate systems.

Gravel Pit covers 150 acres, has a mean and maximum depth of 2.1 and 4.2 m, respectively, and a total volume of 1.30×10^6 m^3. Most of the watershed drains into this basin via three streams (Figure 2). Henderson Lake Ditch drains the eastern-southeastern section of the watershed including outflow from Bixler, Henderson, Beck, Halt, Round and Little Long Lakes. The latter two lakes drain first into Waterhouse Ditch before joining Henderson Lake Ditch. Henderson Lake historically has been the sewage outfall for the town of Kendallville. Total area for the Henderson Ditch segment of the Sylvan Lake watershed is 19.8 mi^2.

The second stream entering Gravel Pit basin is Oviatt Ditch. This stream drains the eastern portion of the Sylvan Lake watershed (42.2 mi^2) including Wible Lake. Just before entering Sylvan Lake, Oviatt Ditch is joined by an unnamed outlet stream for Lakes Latta, Axel, and Grannis. This stream drains the northeastern segment of the watershed with an area of 2.6 mi^2. All three streams enter Gravel Pit basin through a wetland at the eastern end.

Cain basin comprises the southeastern section of Sylvan Lake (area 109.4 acres, volume 1.54×10^6 m^3) and has a mean and maximum depth of 3.5 m and 11.0 m, respectively. This is the deepest basin of Sylvan Lake and it receives no stream drainage. The Upper basin covers 162.3 acres with a volume of 1.84×10^6 m^3. Maximum and mean depth are 5.8 m and 2.8 m, respectively. This basin lacks any stream inflow and receives the bulk of its water from Gravel Pit and Cain basins.

The western most basin of Sylvan Lake is the Lower basin with a mean and maximum depth of 4.2 m and 7.3 m, respectively. It is the largest of the four basins covering an area of 166.9 acres and a volume of 2.85×10^6 m^3. With the exception of a small segment of the watershed draining through Barr Lake, the bulk of the water entering this basin is from the three upstream basins through a constricted area called the Narrows. The outlet for Sylvan Lake is at the western end of the Lower basin. The total watershed area for Sylvan Lake is extremely large (32.8 mi^2), and the lake has a mean residence time of 159 days. Legal lake level has been established at 916 feet above msl and is controlled by the

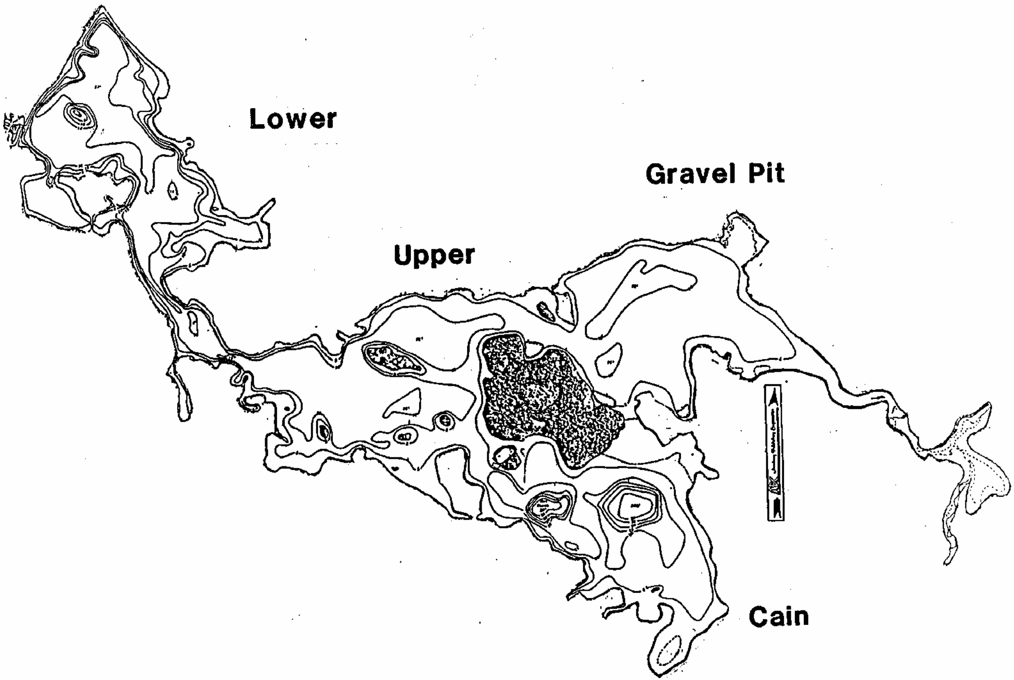


Figure 1. Map of the Individual Basins of Sylvan Lake.

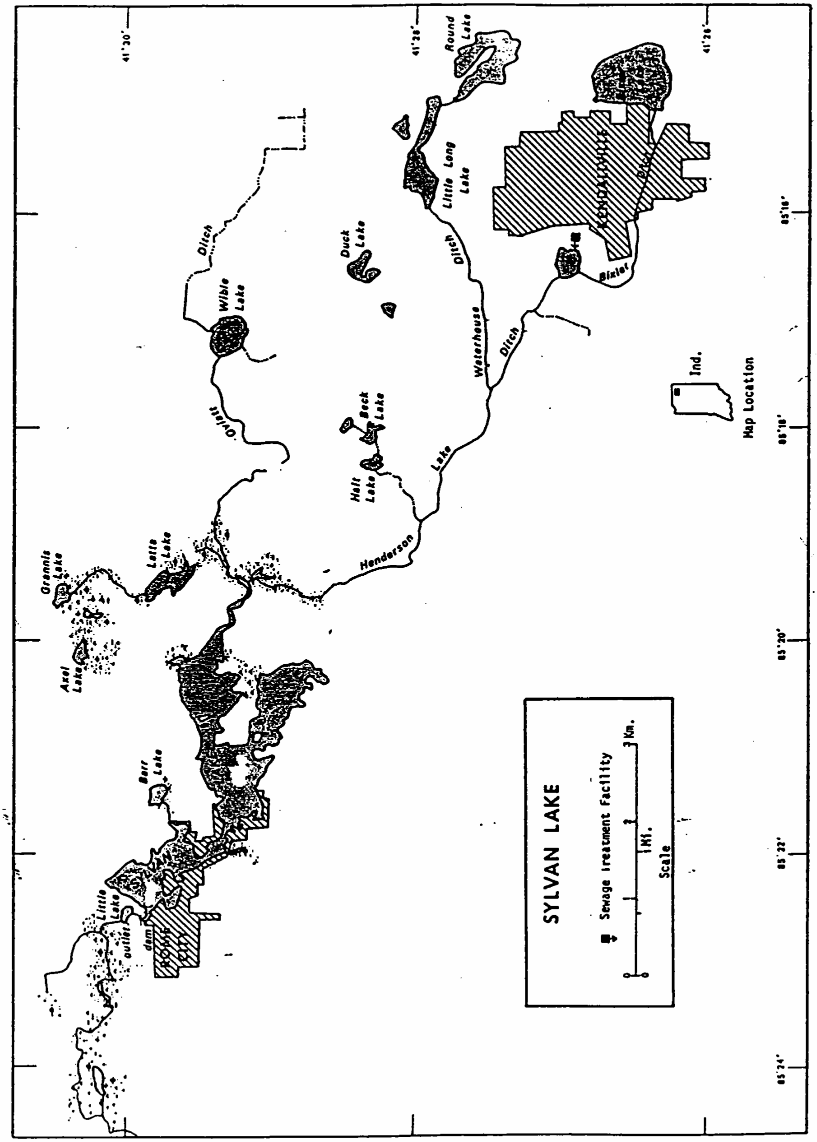


Figure 2. Map of the Sylvan Lake Watershed Including Stream Sampling Stations. Map Adapted from USEPA (1975).

dam at the outlet from the Lower basin.

The 1975 Indiana Eutrophication Index value for Sylvan Lake was calculated as 62, placing the lake in the category of worst water quality (Class Three). As will be discussed in this report, Sylvan Lake has experienced extreme cultural eutrophication and has been the subject of several investigations to reverse this condition. The present study was initiated because of lake residents' desire to develop a sound management plan for both the lake and the surrounding watershed that would not only reduce nutrient inputs but also improve the trophic condition of the lake.

This report is designed to define the current water quality of Sylvan Lake and to evaluate the current condition in light of the history of cultural eutrophication and management practices. Accordingly, it has been separated into three subsections. The first section presents a detailed examination of the historical database on the water quality for Sylvan Lake. The second section summarizes the water quality analyses conducted as part of the 1988 investigation of Turnbell Engineering and compares values to earlier studies. Management implications of my analysis of past and current water quality constitute the third section of the report.

Historical Water Quality

Historical Database and a History of Cultural Eutrophication

A total of 32 separate studies were conducted on the Sylvan Lake between 1927 and 1988 for which data were available (Table 1). The Indiana Department of Natural Resources constructed a bathymetric map for Sylvan Lake in 1927, but collection of water quality data on the lake did not begin until 1937. The Indiana Department of Natural Resources surveyed the fish community 8 times after 1967 and in several of these surveys included data on water chemistry and macrophytes. The Indiana Department of Environmental Management visited the lake once in the mid-1970's to collect water chemistry and biological data for construction of a eutrophication index for classifying the lake relative to other lakes in the state and performed a detailed investigation of the lake in 1976. The lake has been a favorite site of investigation by university researchers since 1939, with Indiana University, Purdue University and Manchester College having conducted 3, 2, and 1 studies, respectively. By far, the most detailed studies were done by Indiana University investigators. No records of bacterial sampling in the lake could be found in the files of the Noble County Health Department. Sylvan Lake was part of the National Eutrophication Survey conducted by the United States Environmental Protection Agency in 1973.

The principal reason for the numerous studies at Sylvan Lake is directly related to the severity its cultural eutrophication. Between the time of its formation in 1839 and 1930, Sylvan Lake was a popular recreational area and no water quality problems were noted (Table 2). By 1930, however, macrophyte growth in the lake was considered excessive, and lake residents were becoming concerned by potential health problems with the lake. This concern prompted investigations in 1931 and 1932 that determined that the lake was unfit for swimming and that the cause of the deterioration of water quality was sewage discharge from Kendallville into Henderson Lake and eventually into Sylvan Lake via Henderson Lake Ditch. It was suggested that Kendallville construct a sewage treatment plant. Numerous investigations from the 1930's documented declining water quality directly related to sewage discharge. As late as 1954, raw sewage was frequently bypassing the sewage treatement plant and being discharged directly into Henderson Lake.

Massive macrophyte and algal problems were noted during the 1950's prompting lake residents to develop a management plan. Winter drawdown was permitted during 1958-60, and this was followed by a program of chemical control of plant growth. From 1962 to 1968, the lake association used in

Table 1. Chronology of Investigations at Sylvan Lake

1927	Indiana Department of Conservation. Construction of bathymetric map for Sylvan Lake.
1937	Indiana Department of Conservation. Lake survey to evaluate nutrient enrichment from Kendallville sewage.
1939	Indiana University. Examination of bluegill growth rates. Published by W.E. Ricker (1942).
1961-63	Indiana State Board Health. Five sampling events for water chemistry from Sylvan lake and tributary streams and lakes. Unpublished data of John Winters published by Wetzel (1966).
1962-68	Sylvan Lake Association. Approximately 30 tons of copper sulphate used for phytoplankton control.
1963	Indiana University. Physical/chemical parameters and algal productivity for April 1963-March 1964. Published by R.G. Wetzel 1966.
1963	Indiana State Board of Health. Phytoplankton identification and abundance at 5 stations. Unpublished data by John Winters.
1965	Indiana University. Assessment of growth of bluegill. Published by S. Gerking (1966).
1967	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1970	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1973	United States Environmental Protection Agency. Physical/chemical parameters, phytoplankton, watershed nutrient loading, nutrient budget as part of National Eutrophication Survey.
1974-75	Indiana Department of Natural Resources. Drawdown of lake during fall-winter for debris removal and installation of sewer lines.
1975	Indiana State Board of Health. Survey of several physical/chemical parameters and algal abundance and composition for construction of BonHomme eutrophication index for Sylvan Lake.

Table 1. (Continued).

1975-76	Indiana Department of Natural Resources. Drawdown of lake during winter to install sewer lines.
1976	Indiana State Board of Health. Physical/chemical parameters, phytoplankton, primary productivity, algal assay procedure.
1976	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1976	Investigations by Indiana Department of Natural Resources, Indiana State Board of Health, and Manchester College (W. Eberly), and Sylvan Lake Association to evaluate whether winter drawdown of lake could improve water quality and reduce nutrient loading.
1976	United States Geological Survey. Construction of bathymetric map for Sylvan Lake.
1976-81	Indiana Department of Natural Resources. Annual winter drawdown of lake to reduce nutrient loading from sediments.
1977	Indiana Department of Natural Resources. Survey of fish community, creel, physical/chemical parameters, macrophyte composition.
1977	Purdue University. Physical/chemical parameters for assessing nutrient loading and trophic state. Published by A. Spacie and J.M. Bell (1985).
1978	Indiana Department of Natural Resources. Survey of fish community.
1980	Indiana Department of Natural Resources. Survey of fish community.
1981	Purdue University. Review of chemical and biological database, calculation of Vollenweider model and Carlson trophic state index, management recommendations. Published by Harshbarger (1981).

Table 1. (Continued).

1981	Indiana Department of Natural Resources. Survey of fish community.
1984	Indiana Department of Natural Resources. Rotenone treatment of lake and tributaries with rotenone to eliminate carp and small black crappie. Restocking with largemouth bass (54,000 fingerlings, 2,800 subadults, 666 adults), 870,000 bluegill fingerlings, 62,000 redear fingerlings, and 25,000 channel catfish (3-14 inches).
1985	Indiana Department of Natural Resources. Survey of fish community, macrophyte composition.
1985	Indiana Department of Natural Resources. Stocking of 30,000 largemouth bass fingerlings, 23,000 channel catfish and 2 million walleye fry. Impose 14 inch minimum size limit for largemouth bass.
1986	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1986	Indiana Department of Natural Resources. Stock lake with 2 million walleye fry.
1987	Indiana Department of Natural Resources. Survey of fish community, physical/chemical parameters, macrophyte composition.
1987	Indiana Department of Natural Resources. Stock lake with 68,000 walleye fingerlings (1.5-2 inches).
1988	Indiana Department of Natural Resources. Jed Pearson conducted a detailed investigation of short-term changes in water clarity.

Table 2. Sylvan Lake History of Cultural Eutrophication.

1837	Indiana Legislature authorizes creation of a reservoir at Rome City to serve as feeder for a proposed Michigan and Erie Canal from Michigan City to Fort Wayne.
1839	Completion of dam forming Sylvan Lake.
1870	Lake popular resort by now. Chautauqua programs held at lake 1870-1906.
1904	Construction of present concrete dam. Previous dam failures were noted in 1839 before completion of lake, 1844, 1855, and 1877.
1906	Lake continues to be popular summer resort and fishing area. End of Chautauqua programs.
1930	Macrophyte growth rich in the lake. Residents concerned about health problems.
1931	State Board of Health survey indicates that Sylvan Lake is unfit for bathing as a result of untreated sewage entering the lake from Kendallville.
1932	Mayor and City Council of Kendallville petitioned to clean Henderson Lake and Henderson Ditch. State Board of Health recommends immediate construction of a sewage treatment plant for Kendallville.
1934	It is concluded that Henderson Lake is grossly polluted from sewage. WPA funds sought for construction of Kendallville sewage treatment plant. Some citizens file injunction to halt STP construction.
1936	Survey reports massive algal bloom at eastern end of Sylvan Lake resulting from nutrients delivered by Henderson Ditch.
1937	Lake survey conducted by the Indiana Department of Conservation concludes that problem with lake is nutrient enrichment from Kendallville sewage that flows without treatment via Henderson Lake Ditch into Sylvan Lake.

Table 2 (Continued).

1939	W.E. Ricker of Indiana University noted that while bluegill in the lake display good growth rates, winter fish kills are common as a result of sewage discharge into the lake.
1941	Indiana Legislature passes H.B. 273 prohibiting lowering of Sylvan Lake.
1945	Phosphate detergent use becomes popular. Phosphate content in sewage doubles by late 1960's.
1954	Discharge of raw sewage to Henderson Lake via a bypass is found to be common occurence.
1958	Noble County ordinance requiring all new developments to obtain a permit for sewage disposal takes effect.
1958	Massive bloom of blue-green algae (Anabaena) during June. Excessive growth of pondweed and Chara in sheltered bays and coves. Discovery of 40-50 tile systems discharging into the lake. Period of low water.
1960	Periodic algal blooms possibly resulting from increased storm water discharge from Kendallville.
1958-60	Lake lowered (winter?) by request of Sylvan Lake property owners with concurrence of court.
1961	Algal blooms begin in early spring and persist through October. Survey indicates that coliform bacteria levels in lake are within standards for bathing.
1962-68	Sylvan Lake Association uses in excess of 30 tons of copper sulphate for algal control.
1963	Weed control permit issued by state.
1964	Six barrels of arsenic poison applied for macrophyte control.
1966	S. Gerking of Indiana University notes that bluegill of lake among fastest growing in U.S.
1966	R.G. Wetzel of Indiana University notes that Sylvan Lake is one of most productive temperate lakes in the world.

Table 2 (Continued).

1969	Lake closed during August by Noble County Health Department due to contamination by Kendallville STP. STP was overloaded. Kendallville told to update facilities and install phosphate removal system.
1973	Massive algal blooms reported as late as November.
1974	Lake drawdown from July 1974 to March 1975 for debris removal and installation of sewer lines.
1975-76	Lake drawdown during winter to install sewer lines.
1976-81	Annual winter drawdowns to reduce nutrient loading from sediments.
1984	Rotenone treatment of lake and tributaries with rotenone to eliminate carp and small black crappie. Restocking with largemouth bass (54,000 fingerlings, 2,800 subadults, 666 adults), 870,000 bluegill fingerlings, 62,000 redear fingerlings, and 25,000 channel catfish (3-14 inches).
1985	Stocking of 30,000 largemouth bass fingerlings, 23,000 channel catfish and 2 million walleye fry. Impose 14 inch minimum size limit for largemouth bass.
1986	Stocking of lake with 2 million walleye fry.
1987	Stocking of lake with 68,000 walleye fingerlings (1.5-2 inches).

excess of 30 tons of copper sulphate for plant control and even resorted to an arsenic based chemical (6 barrels) during 1964. It appears that this chemical control program promoted even more severe algal blooms in the lake resulting in a complete shading out of all rooted submersed vegetation. By 1966, R.G. Wetzel noted that the lake was one of the most productive (eutrophic) lakes in the temperate region worldwide. It was during this period that carp increased to become the dominant fish on a weight basis.

Winter drawdowns were conducted first in 1974-1975 for removal of debris and installation of sewer lines and were continued annually between 1976 and 1981 with the hope of reducing nutrient loading from the lake sediments. The second management technique used at Sylvan Lake involved a selective chemical eradication (rotenone) for rough fish in 1984 followed by gamefish stocking in 1984, 1985, 1986 and 1987. The success of these management programs will be evaluated throughout this report. It should be noted, however, that submersed aquatic macrophytes began to recolonize shallow areas of Sylvan Lake in the late 1980's likely associated with increased water clarity and suggests some recent improvement in water quality.

Physical/Chemical Parameters

A total of twenty physical and chemical parameters have been measured at Sylvan Lake at a frequent enough intervals to be useful in delineating historical trends (Table 3). The most detailed data on seasonal changes in the temperature regime of individual basins of Sylvan are those of Wetzel (1966) for 1963-1964 (Figure 3). All three basins that he examined displayed a dimictic thermal regime (mixing two times per year, once each during spring and fall), but the length of the stratification was directly related to the depth of the individual basins. Cain basin is deepest and remained stratified for the longest period, while Gravel Pit displayed the shortest period of stratification, July through September and again during winter once the lake iced over. Thus, Gravel Pit has the greatest likelihood of recycling nutrients from bottom waters and sediments for the longest period each year. This is important given that this eastern most basin receives the bulk of the nutrient loading to the lake, and its water flows through both the Upper and Lower basins on its way to the outlet.

Secchi depth transparency is a good estimator of either inorganic turbidity from suspended sediment or algal biomass. As Secchi values have historically been recorded during summer at Sylvan Lake, it is likely that they reflect algal biomass rather than suspended inorganic sediment. It is expected that Secchi values should get progressively lower throughout summer as algal biomass builds in response

Table 3. Historical Physical/Chemical Data for Sylvan Lake for the Period 1961-1988.

Sylvan - Lake Historical Data		1961	1962	1963	1964	1967	1970	1973	1975	1976	1977	1979	1980	1983	1985	1986	1987	1988
Secchi	feet					2.4	1.7	2.6		2.6	2.6			1.5	7.5	10.5	5.5	2.1
Mean Dissolved Oxygen	mg/L					4.7	7.4	7.6		6	7	5.5	5.7	8.9		5.6	6	4.7
Alkalinity	mg/L as CaCO3					172	243	162		212	231	137	137			197	138	130
pH						7.3		8.4		7.9	8	8.6	8.8	7.7		8.9	8.5	7.6
Conductivity	umhos/cm							530									618	
Ca	mg/L			49	67	138												
Fe	mg/L				0.08	0.1												
K	mg/L			4	3	3												
Mg	mg/L			18	21	118												
Mn	mg/L				0.05	0.7												
Na	mg/L			46	48	35												
Cl	mg/L			55	68	51												
SO4	mg/L			40	41	56												
Total Phosphorus	mg/L	5.8	0.8	1.6	1.6	1.9		0.37	0.07	0.13	0.09		0.09			0.17	0.13	0.09
Ortho Phosphorus	mg/L							0.036										0.05
Nitrate-N	mg/L	0.83			0.2	0.3												0.06
Ammonia-Nitrogen	mg/L							0.146		0.4						0.38	0.29	0.3
Total Kjeldahl N	mg/L							3.16		1.4								1.02
Nitrite-Nitrate	mg/L							0.054		0.1						0.1	0.2	0.015
Chlorophyll	mg/m3							54.4		26.7								0.0036

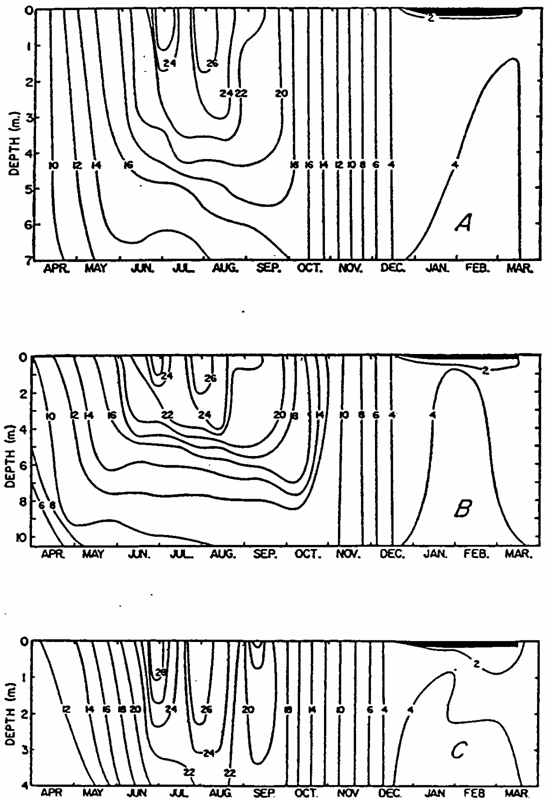


Figure 3. Monthy Vertical Distribution of Temperature (^{o}C) for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

to steadily increasing temperature. The detailed examination of Secchi transparency during the summer of 1987 by Jed Pearson of the DNR clearly displays this pattern as algal biomass builds up to a peak during July and August (Figure 4). Such intermonthly differences must be kept in mind when evaluating historical data trends. Fortunately, Secchi values for most years were based on multiple sampling events and may minimize this potential source of error (Table 3, Figure 5). Mean Secchi values from 1967 through 1981 ranged from 1.7 to 2.6 feet, but a sharp increase in values was noted in 1985 with values remaining high through 1988 (5.5-10.5 feet). It is interesting to note that transparency increased immediately following the fish eradication program of 1984. Judging from the 1981 value, it appears that the lake drawdown program of the late 1970's had little positive effect on water clarity. Finally, even though the Kendallville sewage treatment plant was updated in the early 1970's, water clarity and presumably algal biomass in the lake appears to have been unaffected.

The most detailed examination of seasonal changes in light penetration for Sylvan Lake is that of Wetzel (1966) for 1963-63 (Figure 6). Of the three basins examined, Gravel Pit had the greatest light extinction thoughout the year presumably due to the greater algal biomass associated with proximity to stream inlets and greater internal cycling due to its shallow depth and poor stratification. Light penetration in all three basins was poorest from June through the end of September, the period of greatest algal biomass.

As with Secchi disc transparency, mean water column dissolved oxygen values are expected to decrease throughout the summer in response to increasing temperature and algal production. Such a pattern was clearly demonstrated by Wetzel (1966) for 1963-64 (Figure 7). All three basins clearly displayed profundal deoxygenation (loss of oxygen in bottom waters) during mid summer, but only Gravel Pit failed to display any winter deoxygenation. All three basins also displayed periods of supersaturation of oxygen in surface waters associated with blooms of phytoplankton (Figure 8). Such high productivity was found during early June and September but was most pronounced in all three basins during late winter at the end of ice cover. This pattern was apparently common at Sylvan Lake since at least the early 1930's because Ricker (1942) suggested that winter fish kills were common during the mid and late 1930's as high photosynthetic activity under the ice resulted in deep water anoxia.

A good measure of the degree of eutrophication is provided by the extent of water column anoxia (absence of oxygen) in mid summer (Table 4). While only the deepest section of Cain basin displayed any anoxia during May 1963,

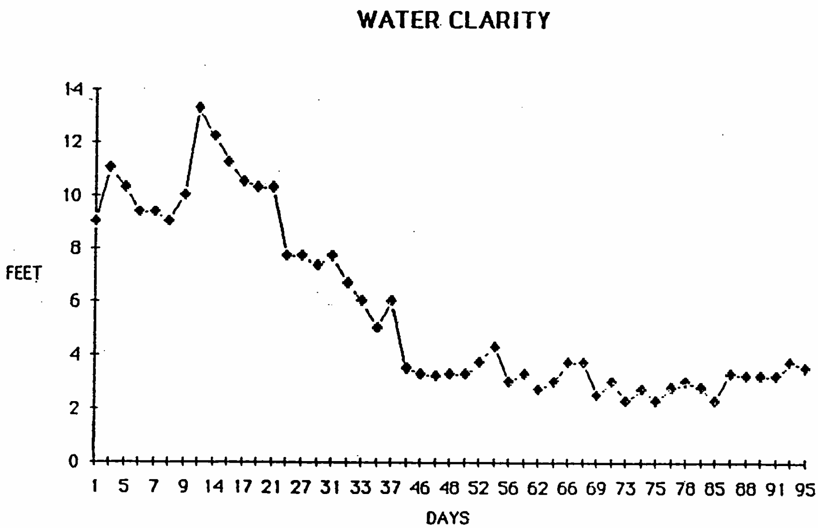


Figure 4. Water Clarity in Sylvan Lake During 1987 Based on Averages of Three Locations Per Day as Published in Pearson (1987). Day 1 Corresponds to May 18, 1987.

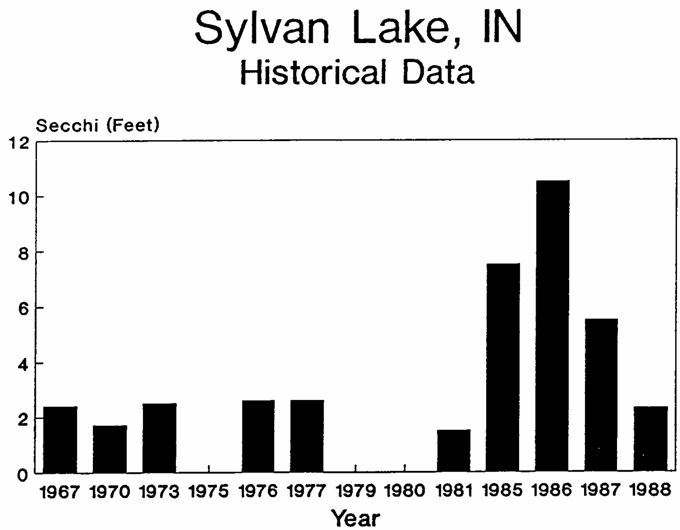


Figure 5. Historical Changes in Secchi Transparency at Sylvan Lake for the Period 1967-1988.

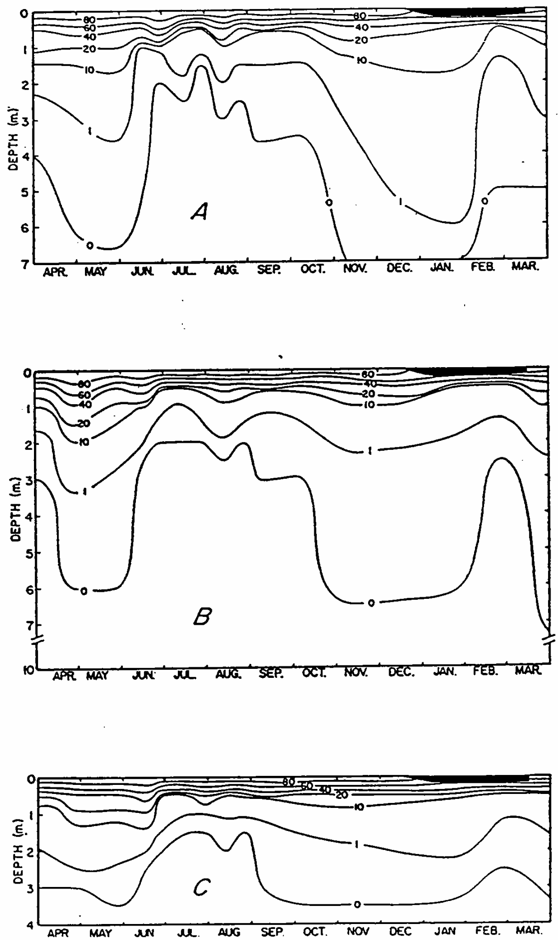


Figure 6. Monthy Vertical Distribution of Percent Light Penetration for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

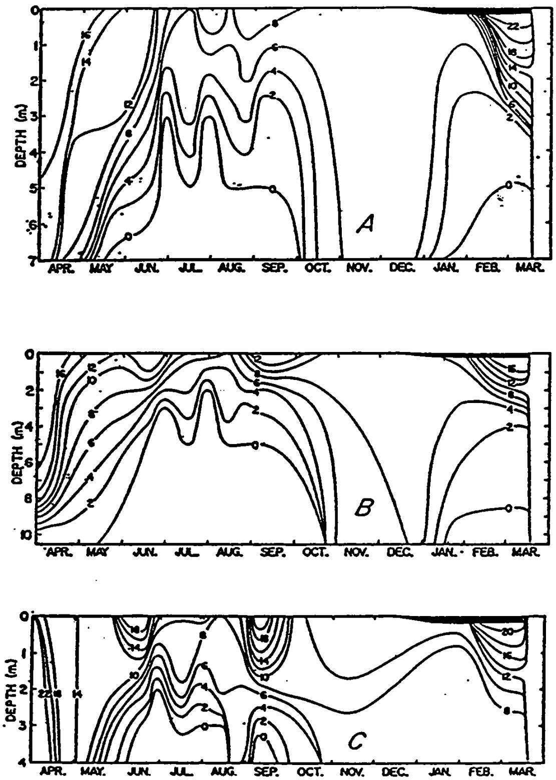


Figure 7. Monthy Vertical Distribution of Dissolved Oxygen Concentrations (mg/L) for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

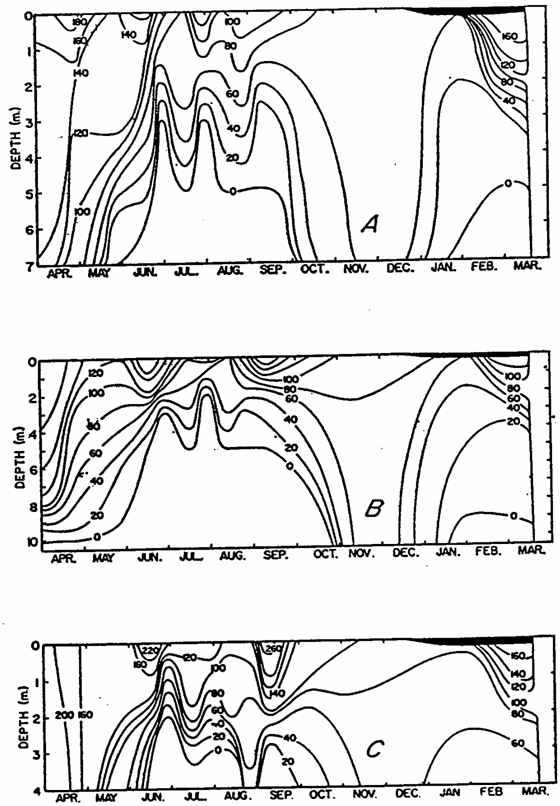


Figure 8. Monthy Vertical Distribution of Percent Saturation of Dissolved Oxygen Concentrations (mg/L) for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

Table 4. Historical Records of Water Column Anoxia in Sylvan Lake, IN

Observation		Initial Depth of <1 mg/L Dissolved Oxygen
May:		
1963	Gravel	Bottom
	Cain	31 feet
	Lower	Bottom
1988	Gravel	10 feet
	Cain	Bottom
	Lower	13 feet
June:		
1963	Gravel	6 feet
	Cain	10 feet
	Lower	18 feet
1976		13 feet
1977		15 feet
1986		15 feet
1987		15 feet
July:		
1963	Gravel	10 feet
	Cain	10 feet
	Lower	15 feet
1967	Gravel	Bottom
	Cain	15 feet
	Lower	15 feet
1970	Gravel	Bottom
	Cain	15 feet
	Lower	15 feet
1976	Cain	15 feet

Table 4. (Continued)

<u>August</u>:

1963	Gravel	10 feet
	Cain	15 feet
	Lower	15 feet
1976		13 feet
1986		15 feet
1988	Gravel	8 feet
	Cain	8 feet
	Lower	8 feet

<u>September</u>:

1963	Gravel	10 feet
	Cain	13 feet
	Lower	15 feet

<u>October</u>:

1963	Gravel	Botton
	Cain	Bottom
	Lower	Bottom
1973		10 feet

serious depletion of oxygen was noted during May 1988 in the same three basins. Anoxia was common in all three basins by June during 1963 as well as in all later studies. Development of anoxic conditions below 10-15 feet depth during July-September has characterized Sylvan Lake since at least 1963. It is interesting to note that the anoxic conditions below 8 feet during 1988 are likely due to the drought and heat conditions of that year rather than a reflection of a change in trophic conditions from that of previous years.

Mean water column oxygen values were lower for 1988 than for all previous surveys except 1967 (Table 3). Values have oscillated a great deal during the past 21 years, but no trend was apparent that could be related to past management practices. It is interesting to note, however, that unlike Secchi transparency, there was not a marked change in mean dissolved oxygen following the fish eradication program of 1984. Unfortunately, the limited database on oxygen is insufficient to evaluate this effectively.

Alkalinity, a measure of the carbonate buffering capacity of lakes, has oscillated throughout the 21 year period between 1967 and 1988 but does not appear to have changed consistently relative to any management practice (Figure 9, Table 3). Wetzel (1966) presented a detailed examination of seasonal alkalinity changes in Sylvan Lake for 1963-64 (Figure 10). The seasonality of this parameter was closely related to stratification periods with a build up in anoxic profundal areas during mid summer. As will be discussed later, alkalinity can be a useful parameter for assessing changes in watershed delivery of erosion products through human activities. It is interesting to note that no apparent increase in alkalinity was found in Sylvan Lake during 1963-64 during the period of spring rains and associated increased runoff from the watershed.

Wetzel (1966) also published a detailed seasonality for pH in Sylvan Lake for 1963-64 (Figure 11). Maximum values for this parameter were found in surface waters during mid summer and are a direct reflection of the high algal productivity during the period. Conversely, pH values for the year were lowest in the anoxic profundal zones of the three basins during midsummer reflecting the reducing conditions associated with decomposition of the massive algal rain from the photic zone. Overall, pH has remained at 7-9 for the entire 21 year period for which records exist (Table 3).

Total phosphorus concentrations in Sylvan Lake have changed markedly since 1961 (Figure 12, Table 3). From 1961 through 1967 total phosphorus ranged between 0.8 and 5.5 mg/L, whereas since 1973 values have declined sharply to

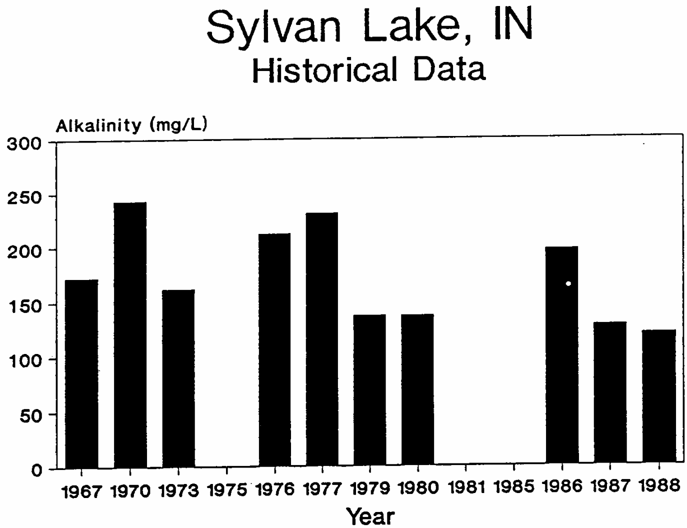


Figure 9. Historical Changes in Total Alkalinity at Sylvan Lake for the Period 1967-1988.

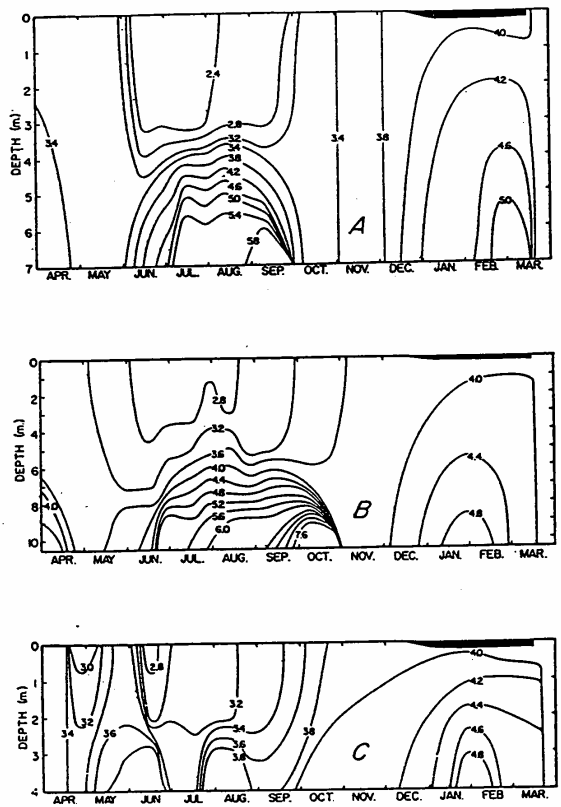


Figure 10. Monthy Vertical Distribution of Total Alkalinity (milliequivalents per liter) for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

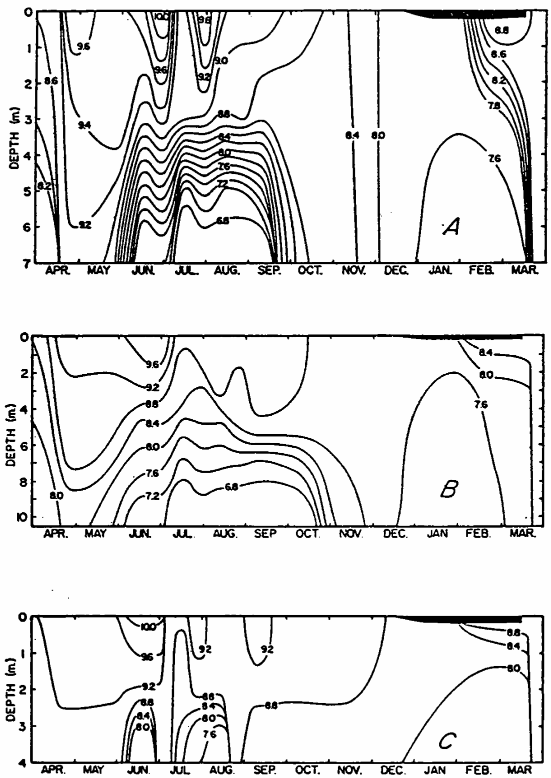


Figure 11. Monthy Vertical Distribution of pH for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

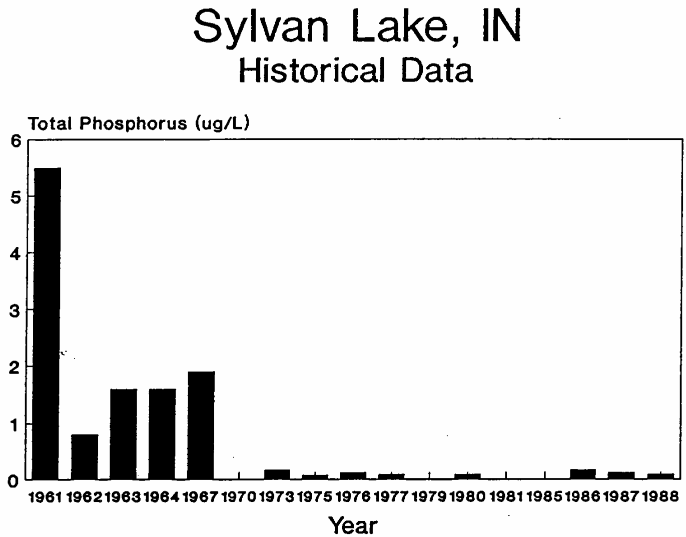


Figure 12. Historical Changes in Total Phosphorus at Sylvan Lake for the Period 1961-1988.

0.07-0.17 mg/L. Such a decline between 1967 and 1973 is likely attributable to the updating of the Kendallville sewage treatment plant, installation of sanitary sewers around the lake, and the state-wide phosphorus detergent ban. Neither the drawdowns of the late 1970's nor the fish eradication program of 1984 appear to have affected phosphorus concentrations in Sylvan Lake.

As evidenced by nitrate, it appears that nitrogen values in Sylvan Lake also have declined in the past 21 years (Figure 13, Table 3). Unfortunately, the database is rather limited and 1988 values may not be broadly representative of current conditions given the extreme heat and drought conditions of that year. The remaining physical and chemical parameters measured at Sylvan Lake were sampled so infrequently as to be of little value in delineating past trends in water quality.

Microbiology

Neither the Noble County Health Department nor the Indiana State Board of Health had any historical microbiological data from Sylvan Lake. Wetzel (1966) did, however, present unpublished data obtained from John Winters of the Indiana State Board of Health for Biochemical Oxygen Demand (BOD) measurements from nine stations in Sylvan Lake and its watershed on 7 September 1961. Values increased from 4.8 ppm above Henderson Lake to 10.0 ppm in Henderson Lake, but decreased quickly to 7 ppm below the lake. Values greater than those of Henderson Lake were found in Waterhouse Ditch (11 ppm) and Cain basin of Sylvan Lake (20 ppm). Unfortunately such limited data are of marginal value for delineating historical trends.

Phytoplankton

Phytoplankton samples were collected four times since 1963. Wetzel (1966) presented unpublished data of John Winters of the Indiana State Board of Health who sampled Sylvan Lake on 3 July 1963. The United States EPA as part of their National Eutrophication Survey sampled phytoplankton during May, August and October of 1973. The Indiana State Board of Health sampled phytoplankton during the summer of 1975, but the data were missing from the departmental files. The final survey of phytoplankton was by the Indiana State Board of Health when samples were collected during June, July and August of 1976.

The dominant taxa in all surveys have been blue-greens with *Anabaena*, *Aphanizomenon*, and *Oscillatoria* the major genera (Table 5). Winter estimated algal abundance in Cain basin during early July 1963 as 14,800/mL, while the survey

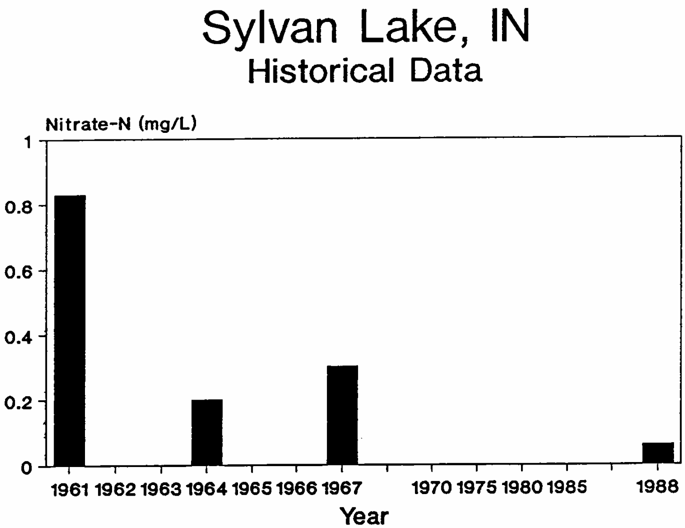


Figure 13. Historical Changes in Nitrate at Sylvan Lake for the Period 1961-1988.

Table 5. Major Phytoplankton Genera in Sylvan Lake.

Algal Group	Genus	1963	1973	1976
Diatoms	Cyclotella	X		
	Melosira		X	
Greens	Ankistrodesmus			X
	Chlamydomonas			X
	Closteriopsis			X
	Coelastrum			X
	Crucigenia			X
	Oocystis		X	X
	Pediastrum			X
	Scenedesmus		X	X
	Staurastrum			X
	Tetraedron			X
	Tetrastrum		X	X
Blue-Greens	Anabaena	X	X	X
	Anacystis			X
	Aphanizomenon	.	X	X
	Chrococcus			X
	Coelosphaerium			X
	Gomphasphaerium			X
	Oscillatoria	X	X	X
	Spirogyra	X		
Cryptomonads	Cryptomonas		X	

of June 1976 sampled a week earlier than the 1963 survey and reported only 2,178/mL. The mean for Cain basin for the whole summer of 1976 was only 4,444/mL. While suggestive that the phosphorus reduction noted earlier (Figure 12) during the early 1970's may have resulted in lower algal biomass by 1976, the limited database does not permit a definitive picture. Other suggestive for a reduction in algal biomass by 1976 is seen for the reduction in the mean summer algal biomass of the Upper-Lower basins from 13,485/mL in 1973 to 7,067/mL in 1976. The only detailed phytoplankton counts for all basins of Sylvan Lake are for 1976 when the individual basins ranked in order of decreasing mean summer algal abundance as: Gravel Pit (22,062/mL), Upper (8,976/mL), Lower (5,159/mL) and Cain (4,444/mL).

The DNR fishery survey of 1967 reported that the "hyperabundance of plankton is considered detrimental to the aesthetic and recreational value of the lake". During the summer of 1966, the Sylvan Lake Association sprayed 3,780 lbs of copper sulphate on each of five occasions but only caused a short term reduction in algal biomass. Algal blooms were common as early as the 1930's, but it was not until the massive weed control program that phytoplankton totally replaced macrophytes as the dominant primary producers in the lake and reached an unmanageable state. This is a classic case of improper weed management promoting an even worse problem with algae.

Primary Productivity

Detailed surveys of phytoplankton primary productivity at Sylvan Lake were conducted during 1963-64 by Wetzel (1966) and 1976 by the Indiana State Board of Health. Algal productivity was limited to only the surficial waters of the three basins examined during 1963 with the basins ranked in order of decreasing depth of the photic zone as Cain, Lower, and Gravel Pit (Figure 14). Productivity displayed a great deal of variability in all basins on a seasonal basis (Figure 15), but Wetzel (1966) noted that winter productivity was still great and represented a great portion of total annual primary productivity.

Wetzel (1966) described Sylvan Lake as "one of the most productive lakes in the temperate region of the world", a rather dubious distinction at best. Likewise, the ISBH survey of 1976 found that only Palestine Lake, Indiana displayed productivity values as high as Sylvan. Interestingly, mean daily productivity for 1963 (1,564 mg C/m^2/day) and 1976 (1,620 mg C/m^2/day) were comparable.

The EPA study of 1973 suggested that nitrogen was the limiting nutrient for phytoplankton growth in Sylvan Lake

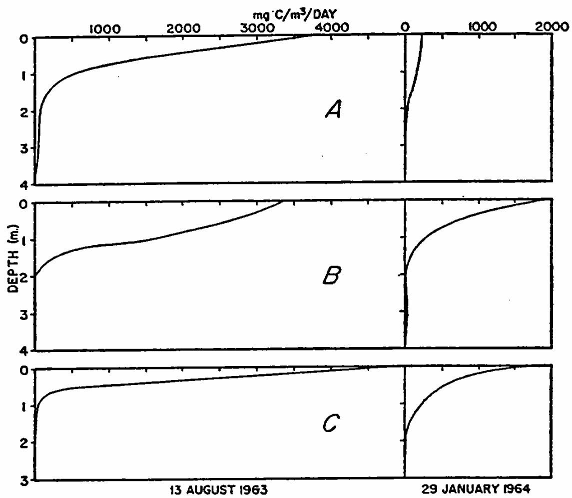


Figure 14. Vertical Variations in the Depth of the Trophogenic Zone for Two Dates in 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

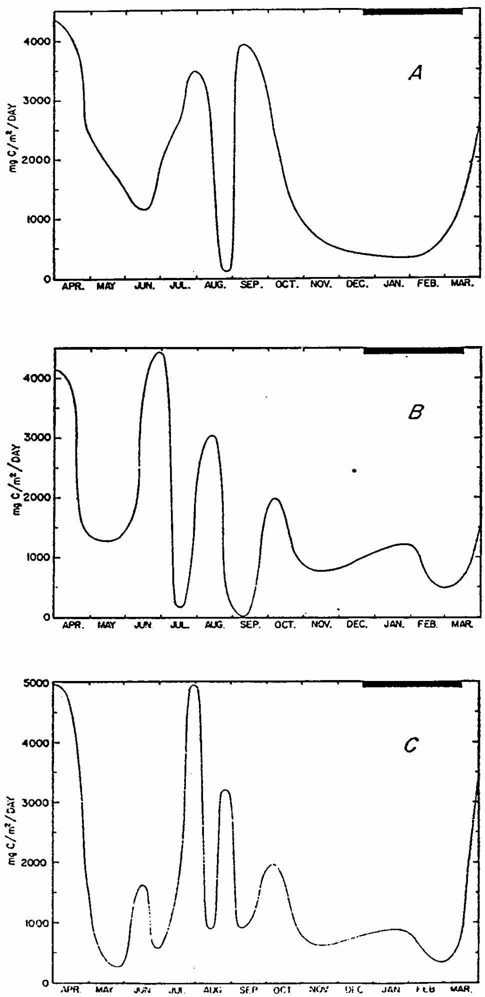


Figure 15. Monthy Vertical Distribution of Primary Production for 1963-1964 in A (Lower Basin), B (Cain Basin) and C (Gravel Pit Basin) as Published by Wetzel (1966).

based on nitrogen to phosphorus ratios, but the ISBH study of 1976 conducted tests using the Algal Assay Procedure with Selenastrum and refuted this suggesting instead that the lake was phosphorus limited. Additional assays are needed to settle this apparent disagreement.

Macrophytes

The macrophyte (aquatic weed) community has been examined seven times since 1967 as part of Indiana Department of Natural Resources fish surveys (Table 6). Plant taxonomic composition appears to have changed markedly since 1985 (Table 6). Submergent macrophyte taxa, which were either absent entirely or rarely encountered, increased markedly after 1985, the first year following the chemical fish eradication program, and became the most taxonomically diverse plant community.

Although aquatic macrophytes were considered a management problem from the 1930's until the 1960's, an over zealous control program initiated by lake residents essentially eliminated weeds completely from the lake by the mid 1960's. By 1967, the DNR survey noted that the lake was algal dominated, submergents were extremely rare and represented chiefly by Wigeon grass, and on the whole the macrophyte community was limited to a shoreline fringe of water lilies and cattails. The progressive demise of the macrophyte continued so that by 1976 submergents were totally absent and emergents were restricted to a shoreline fringe (less than 10% of total lake area) in water less than 2-3 feet deep. A similar observation was made in 1977. It is likely that the demise of the macrophyte community was linked closely to the chemical control program coupled with the drawdowns of the mid to late 1970's.

Macrophytes have been making a progressive comeback since 1985. In that year, several submergent taxa not seen in the lake since at least 1967 were found, and the dominant plant species in the lake was the submergent leafy pondweed (Potomogeton foliosus). Submergents were limited to depths less than three feet, but floating leaved taxa now were able to colonize depths up to four feet. The DNR survey of that noted that while weeds were returning, they were not considered a problem.

By 1986, submergent vegetation was dense in some coves of the lake and floating leaved vegetation was able to extend its growth depth to 6-8 feet. Curly pondweed (Potomogeton crispus) now was the dominant submergent and able to grow to depth of four feet. Finally, by 1987 water clarity had increased to the point that submergent vegetation was able to growth to a depth of 12 feet, and the community was becoming more taxonomically diverse.

Table 6. Macrophyte Species Composition of Sylvan Lake for the Period 1967-1987.

Species	Common Name	1967	1970	1976	1977	1985	1986	1987
SUBMERGENTS:								
Ceratophyllum demersum	coontail	X	X			X	X	X
Elodea canadensis	elodea						X	X
Myriophyllum spp.	water milfoil							X
Najas flexilis	bushy pondweed					X		
Potomogeton crispus	curly pondweed	X	X			X	X	X
Potomogeton foliosus	leafy pondweed					X		
Potomogeton pectinatus	sago pondweed						X	X
Ruppia maritima	Wigeon grass	X						
Vallisneria americana	eel grass					X	X	X
EMERGENTS:								
Peltandra virginica	arrow arum					X	X	X
Typha latifolia	common cattail	X	X	X	X	X	X	X
FLOATING LEAVED:								
Nelumbo lutea	American lotus	X				X	X	X
Nuphar advena	spatterdock	X	X	X	X	X	X	X
Nymphaea tuberosa	waterlily	X	X	X	X	X	X	X
FREE FLOATING:								
Lemna minor	duckweed	X	X			X	X	X
BENTHIC ALGAE:								
Hydrodictyon spp.						X		
Pithophora spp.						X		

Submergent plants during 1987 were coontail, milfoil, and curly pondweed. For the first time, the DNR suggested that aquatic macrophytes were posing some management problems around docks and a limited control program could be initiated.

The successful return of macrophytes corresponded with increased water clarity following the fish eradication program of 1984. The previous drawdowns appear to have further stressed the macrophyte community as to spell the demise of the submergent taxa. Removal of rough fish, especially carp, likely reduced turbidity in the water column due to reduction of sediment resuspension from carp feeding and associated reduced recycling of nutrients from the bottom. The end result was a reduction in algal biomass which permitted light to reach shallow bottom areas thus stimulating macrophyte growth. As will be discussed later, the macrophytes were able to recolonize Sylvan Lake even without a reduction in total phosphorus in the water column. It is interesting that the depth to which macrophytes were able to growth increased progressively annually following carp removal.

Fish

The Indiana Department of Natural Resources surveyed the fish community of Sylvan Lake ten times between 1967 and 1987. Earlier studies of the bluegill population was performed by Ricker (1942) and Gerking (1966). All DNR surveys were based on electrofishing, gill net, and trap collections (Table 7).

A listing of the individual species caught and the contribution of each to total fish abundance and weight caught during DNR surveys from 1967-1987 is presented in Tables 8 and 9, respectively. Although in excess of 27 taxa have been identified from Sylvan Lake, the assemblage has undergone a number of profound changes during at least the past 20 years. Ricker (1942) noted that in spite of fast growth rates for bluegills, there were problems with the fishery of Sylvan Lake as early as the mid 1930's associated with winter fish kills due to excessive algal blooms. By the late 1960's, the fishery of the lake had so deteriorated that carp made up approximately 8% of total fish abundance (Figure 16, Table 8) and in excess of 70% of total fish weight (Figure 17, Table 9). In spite of the drawdowns of the late 1970's, carp continued to contribute greater than 5% of total abundance and 50% of total weight through 1981. Two additional important taxa during this period were pumpkinseed sunfish (10-40% abundance, 2-4% weight) and brown bullheads (5-25% abundance). The Sylvan Lake Conservation Club introduced 250 walleyes (fingerlings to 3 lbs.) in 1963 to prey on the over population of bluegills and pumpkinseeds, but judging by the catch return by 1967,

Table 7. Historical DNR Fish Sampling in Sylvan Lake, IN.

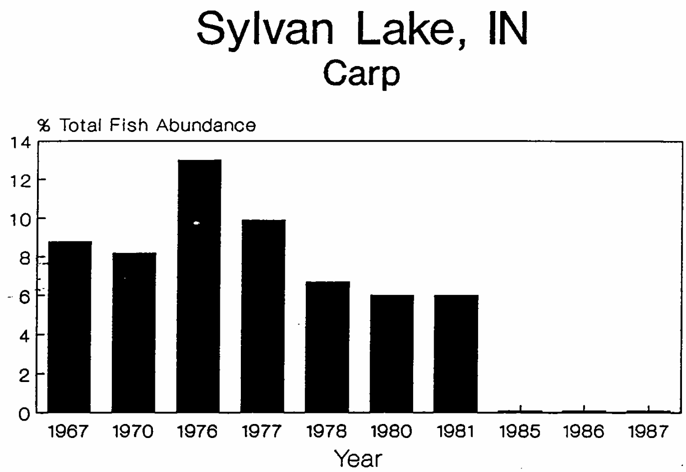
1967	Electrofishing:	3 hrs
	Gillnets:	3 for 96 hrs = 288 hrs total effort
	Traps:	20 = 2,964 hrs total effort
1970	Electrofishing:	3 hrs
	Gillnets:	4 for 96 hrs = 384 hrs total effort
	Traps:	13 = 1,248 hrs total effort
1976	Electrofishing:	1.5 hrs night, 1.5 hrs day
	Gillnets:	4 for 72 hrs = 288 hrs total effort
1977	Electrofishing:	1.25 hrs night, 1 hr day
	Gillnets:	17 for 24 hrs = 408 hrs total effort
1978	Electrofishing:	2.25 hrs
	Gillnets:	4 for 96 hrs = 384 hrs total effort
	Traps:	4 = 288 hrs total effort
1979	Electrofishing:	2.5 hrs
	Gillnets:	288 hrs
	Traps:	192 hrs
1980	Electrofishing:	2 hrs
	Gillnets:	288 hrs
	Traps:	216 hrs
1985	Electrofishing:	3.5 hrs
	Gillnets:	456 hrs
	Traps:	480 hrs
1986	Electrofishing:	1.5 hr night
	Gillnets:	9 for 24 hrs = 192 hrs total effort
	Traps:	8 = 216 hrs total effort
1987	Electrofishing:	.75 hrs
	Gillnets:	5 for 24 hrs = 120 hrs total effort
	Traps:	4 = 120 hrs total effort

Table 8. Percent Contribution of Individual Fish Taxa to Total Fish Abundance at Sylvan Lake for the Period 1967-1987.

Sylvan Lake	1967	1970	1976	1977	1978	1980	1981	1985	1986	1987
Black Bullhead								0.1		
Black Crappie	5.9	28.9	31.1	38	24.2	23.7	37	8.3	0.7	0.6
Bluegill	34.3	13.6	4.1	5.2	13.7	1.8	5	24.1	19	26
Bluntnose Minnow					0.1	0.1				
Bowfin		0.1	0.1	0.1	0.1			0.1		0.1
Brook Silversides					0.1	0.1				
Brown Bullhead	5.5	26.1	0.5	0.6	0.3	1	1	0.1		0.1
Carp	8.8	8.2	13	9.9	6.7	6	6	0.1	0.1	0.1
Channel Catfish		1.9	4.1	4.9	3.5	1.4	1	15	10.6	4.4
Golden Shiner						0.1		0.7	1.5	0.1
Grass Pickeral		0.1	0.1							
Green Sunfish	0.4	2.1	3.2	3.1	1.8	0.3	1	0.7	1.6	1.9
Hybrid Sunfish								0.1		
Lake Chubsucker					0.1			0.2	0.1	0.1
Largemouth Bass	0.8	0.7	2.7	2.6	2.7	1.9	2	24.1	35.7	26.2
Northern Pike										0.1
Pumpkinseed	39.6	11.8	36.3	25	14.3	5.2	5	4.2	2.6	2.7
Redear								3.2	0.1	0.2
Rock Bass									0.1	
Smallmouth Bass		0.1								
Spotted Gar	0.2	0.5		0.1						
Walleye								3.8	11.2	7.7
Warmouth		0.1			0.1				0.3	0.2
White Crappie						1.7	18	0.1		
White Sucker	1.8	1.5	1	4.8	7.3	9.6	8	0.8	1.5	5.8
Yellow Bullhead	0.3	4.1	0.2	0.4	0.1	0.1			0.1	0.3
Yellow Perch	2.5	0.1	3.7	5.2	25.1	45	17	14.1	14.8	23.2

Table 9. Percent Contribution of Individual Fish Taxa to Total Fish Weight at Sylvan Lake for the Period 1976-1987.

	1976	1977	1978	1980	1981	1985	1986	1987
Black Bullhead						0.1	1.8	
Black Crappie	9.2	12.3	9.7	3.9	8.0	8.7	1.2	0.4
Bluegill	0.9	0.9	1.0	0.5	1.0	9.9	5.1	7.5
Bowfin	0.3	0.8	0.4			0.3		0.2
Brown Bullhead	0.2	0.4	0.2	1.0	1.0			0.2
Carp	74.4	62.3	54.4	58.1	58.0	1.0	0.2	1.1
Channel Catfish	6.2	8.5	9.1	9.7	7.0	31.0	13.7	13.1
Golden Shiner						0.3		0.1
Grass Pickeral	0.1							
Green Sunfish	0.3	0.3	0.2	0.1		0.2	0.3	0.6
Lake Chubsucker			0.1			0.4	0.2	0.1
Largemouth Bass	2.4	2.4	2.9	1.5	4.0	22.3	29.7	24.9
Northern Pike								1.4
Pumpkinseed	3.7	3.4	2.9	1.1	1.0	2.3	0.8	0.7
Redear						3.3	0.4	0.3
Spotted Gar		0.4						
Walleye						1.9	6.6	11.9
Warmouth							0.2	0.1
White Crappie				0.5	4.0			
White Sucker	1.8	7.0	10.2	18.3	13.0	7.2	12.3	15.8
Yellow Bullhead	0.1	0.1		0.1			0.1	0.5
Yellow Perch	0.6	1.2	9.0	5.0	3.0	10.9	27.3	21.2



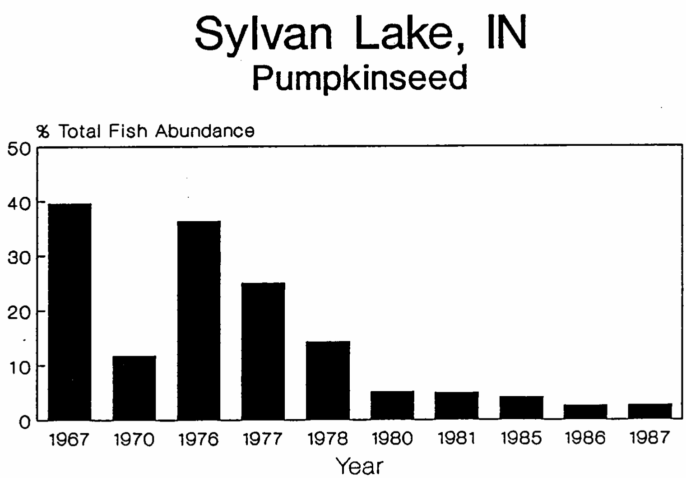
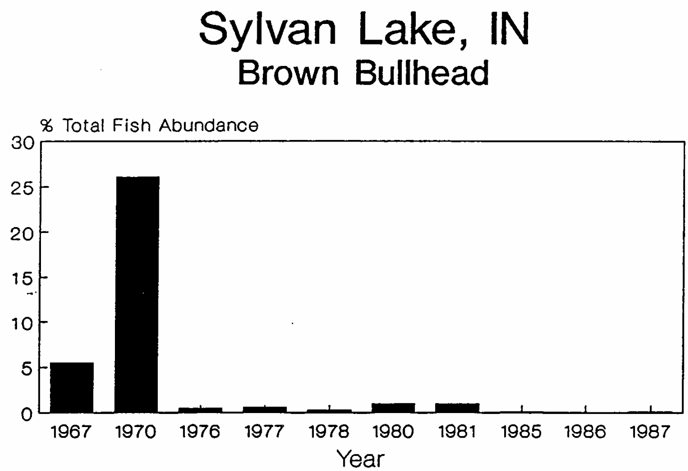
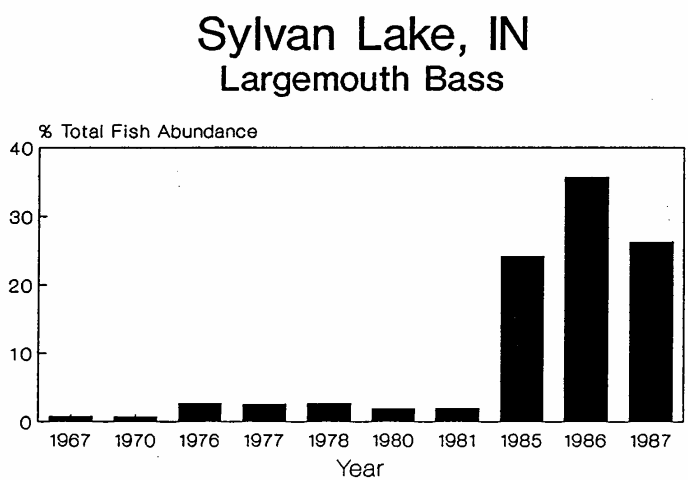


Figure 16. Changes in the Percentage Contribution of Select Species to Total Fish Abundance in Sylvan Lake for the Period 1967-1987.





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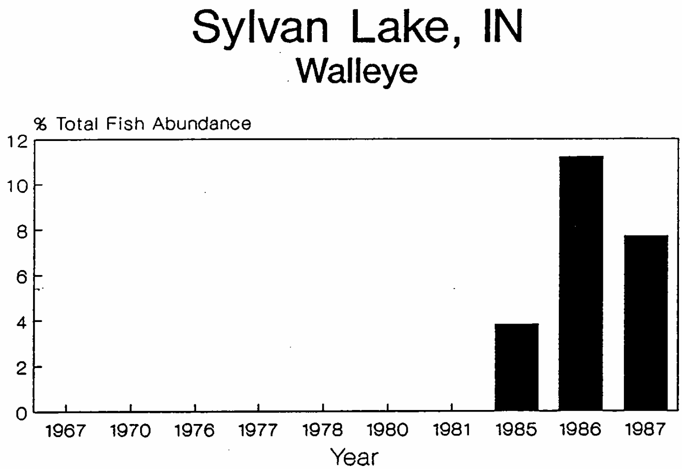

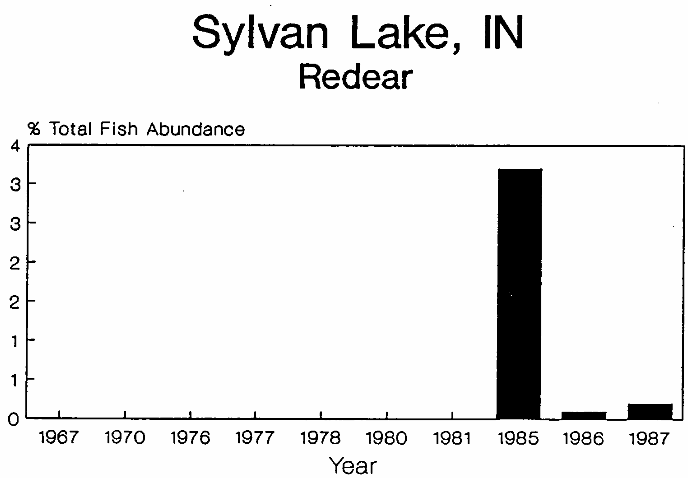

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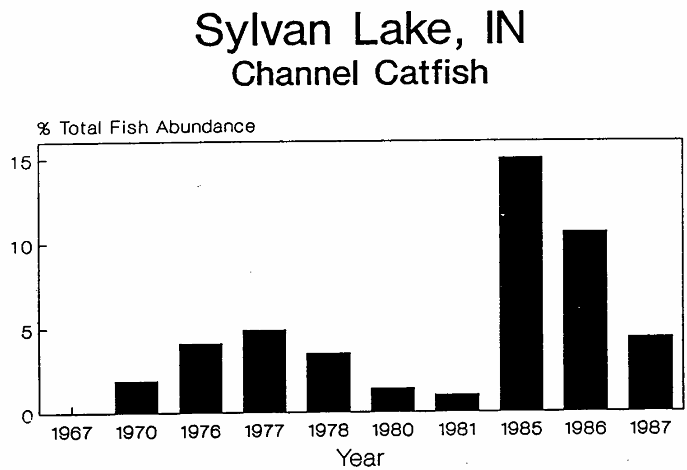

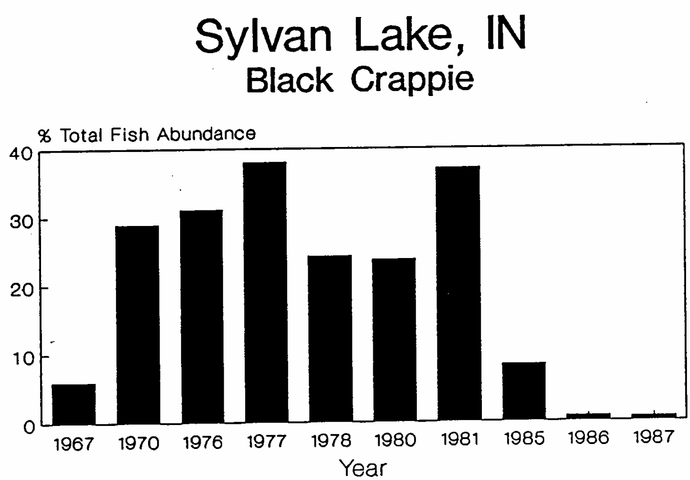

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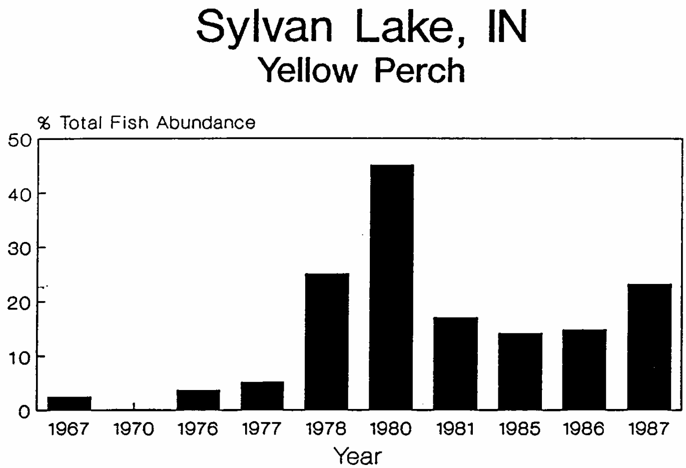

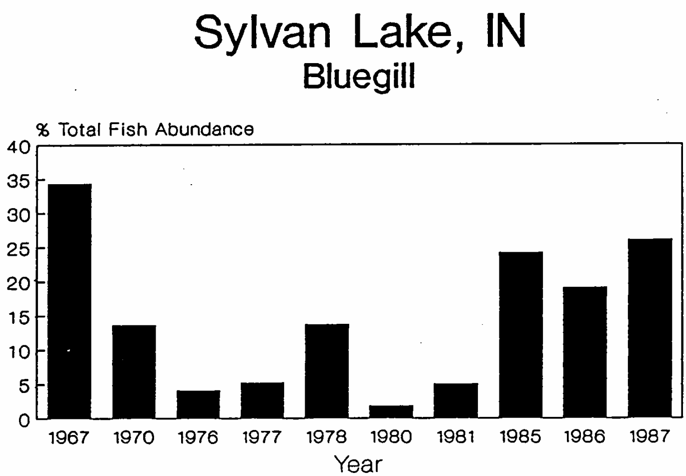

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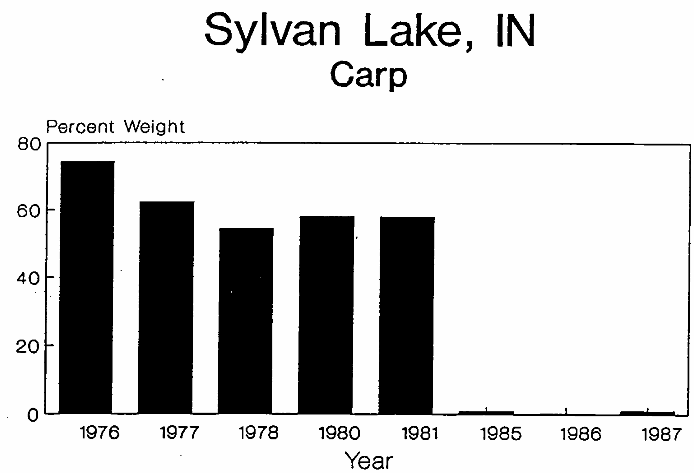


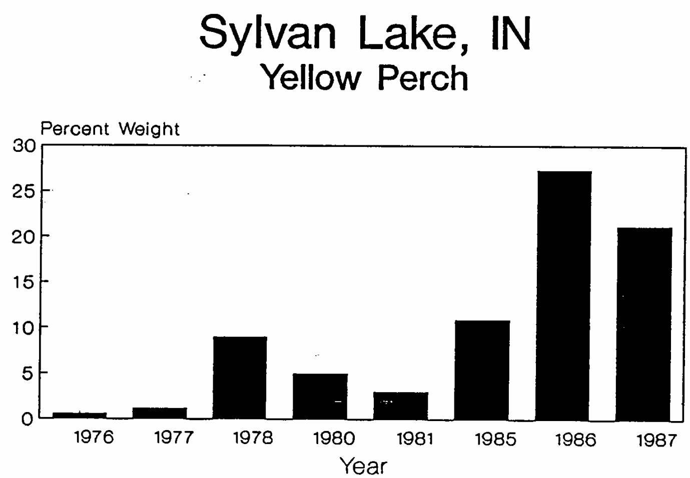
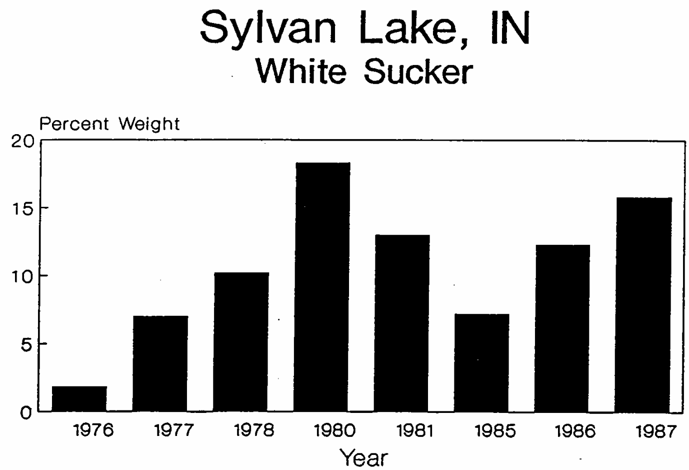
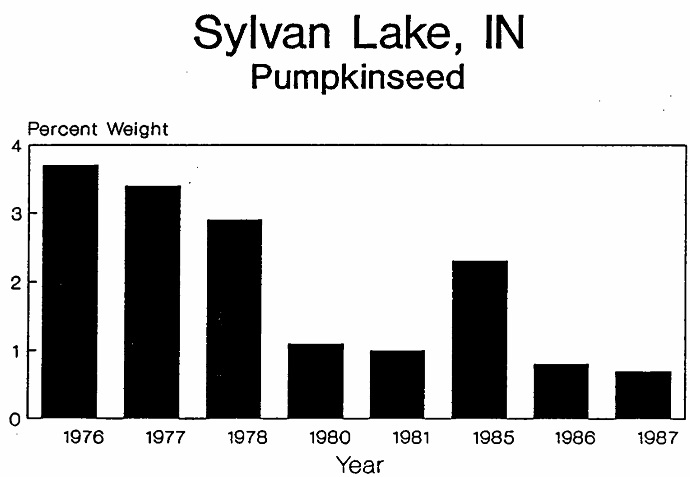


Figure 17. Changes in the Percentage Contribution of Select Species to Total Fish Weight in Sylvan Lake for the Period 1976-1987.





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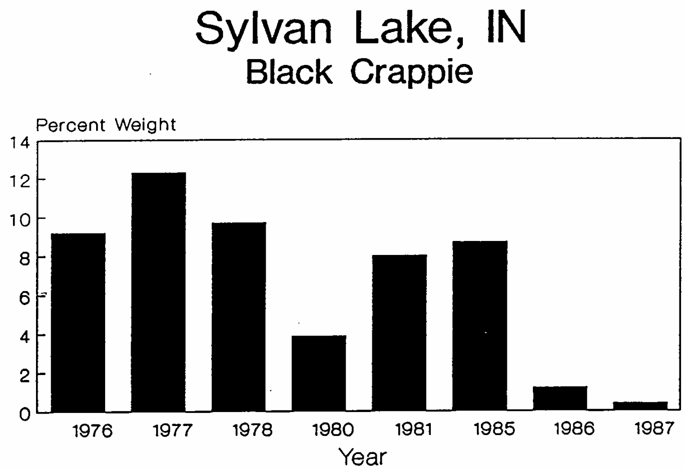

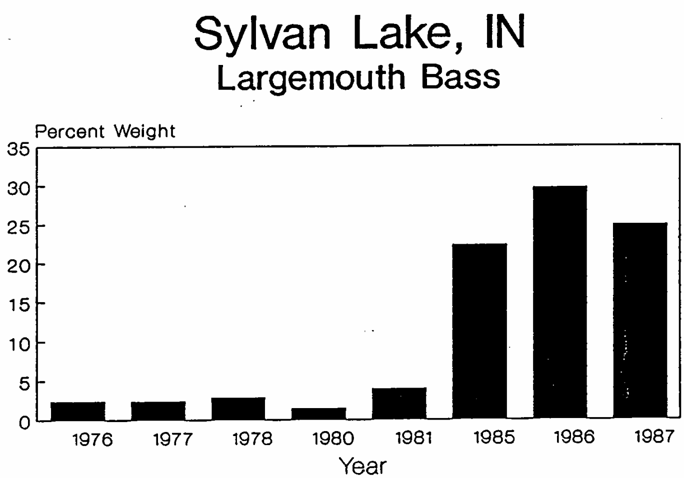

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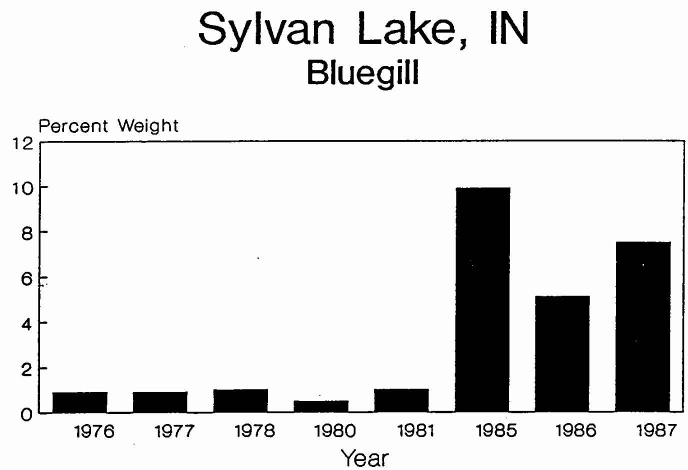

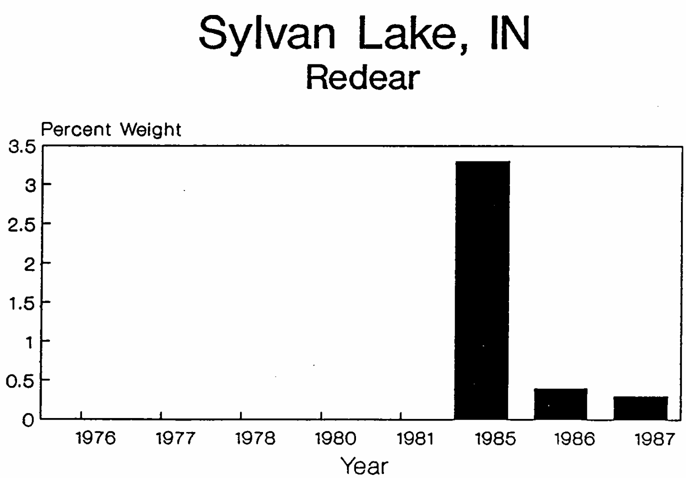

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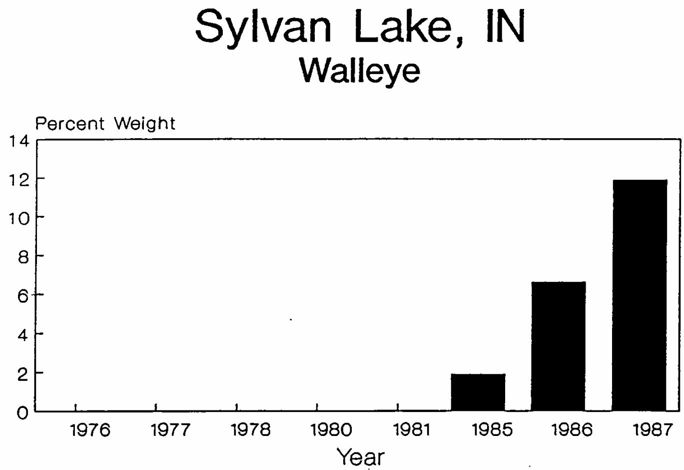


Figure 17. (Continued).

the stocking effort was not successful. The 1970 DNR report suggested that the large carp population was increasing the turbidity of the water through their feeding activity resulting in reduced largemouth bass populations.

The 1970's witnessed a dominance of both fish abundance and weight by black crappie, carp and pumpkinseed sunfish. By 1976, the fishery was considered only marginal due to excessive numbers of pumpkinseeds and carp, and it was suggested that the feasibility of a major fishery eradication program be examined. During 1977, the Sylvan Lake Association paid a bounty of five cents per pound of carp collected and recovered over 21,000 lbs of carp by this program. The DNR continued to suggest that largemouth bass were not able to compete with the large carp in the lake and a fish eradication should be implemented.

By the early 1980's the pumpkinseed population appeared to have declined and the lake was dominated by black crappie, carp, yellow perch, and white suckers. The DNR suggested that the decline of pumpkinseeds and increase of yellow perch, white crappie and white sucker were related to the series of winter drawndowns done in the lake between 1975 and 1981, but felt that the lack of response of either largemouth bass or bluegill populations was evidence that drawdowns did not result in any sustained improvement in the fishery. Growth rates of the latter two taxa during 1981 were considered only 50% and 16% of populations in other northeastern Indiana lakes.

A major fish eradication program was undertaken by the Indiana Department of Natural Resources in 1984 when the lake and its tributaries were treated with 2,500 gallons of rotenone at a cost of $128,000. A month later the lake was stocked with largemouth bass (54,000 fingerlings, 2,800 subadults, 666 adults), bluegill (870,000 fingerlings), redear (62,000 fingerlings), and channel catfish (25,000 3-14 inches). A second fish stocking of largemouth bass (30,000 fingerlings), channel catfish (23,000 fingerlings) and walleye (2 million fry) took place in 1985 followed by a final stockings of walleye in 1986 (2 million fry) and 1987 (68,000 fingerlings 1.5-2 inches). A 14 inch minimum size limit was placed on largemouth bass in 1985 to reduce fishing pressure on this predator.

Carp and white crappie were almost completely erradicated by the chemical control program, and additional taxa including pumpkinseeds (96% reduction), green sunfish (81%), white sucker (91%), and yellow perch (99%) experienced major population reductions. Those taxa increasing following treatment were bluegill (46% increase), channel catfish (91%) and largemouth bass (370%).

The 1984-1987 fish eradication and stocking program has resulted not only in a dramatic improvement in the fishery but has increased water clarity and permitted the reestablishment of submergent macrophytes. As noted earlier, the depth to which macrophytes have been able to grow has increased progressively since 1984. Most importantly, such changes have taken place in spite of the fact that total phosphorus concentrations remained unchanged throughout the period. This project demonstrated that biomanipulation is a cost effective alternative for effective lake management.

Current Water Quality

Methods

Water quality parameters were collected during 1988 on 24 May and 9 August. A single sampling station was established in Cain, Gravel Pit, and Lower basins near the point of maximum water depth in each (Figure 1). Dissolved oxygen and temperature profiles were determined with a YSI oxygen meter, and light transmission was estimated with a Secchi disc.

Water samples for chemical, bacteriological and chlorophyll analyses were taken from composite samples of the water column. After determining the depth of the thermocline using a YSI temperature-oxygen meter, a Kemmerer bottle was used to collect water from equal portions of the epilimnion, metalimnion, and hypolimnion. Conductivity, pH, and alkalinity were determined in the field on subsamples of this composite, and the remainder of the sample was iced for transport to the laboratory for determination of ammonia, total Kjeldahl nitrogen, nitrate, nitrite, total phosphorus, ortho phosphorus, suspended solids, chlorophyll, 5-day BOD, and bacteria counts. All analyses were performed according to Standard Methods (APHA 1985). Data for physical and chemical parameters for individual basins during the 1989 survey are presented in Table 10.

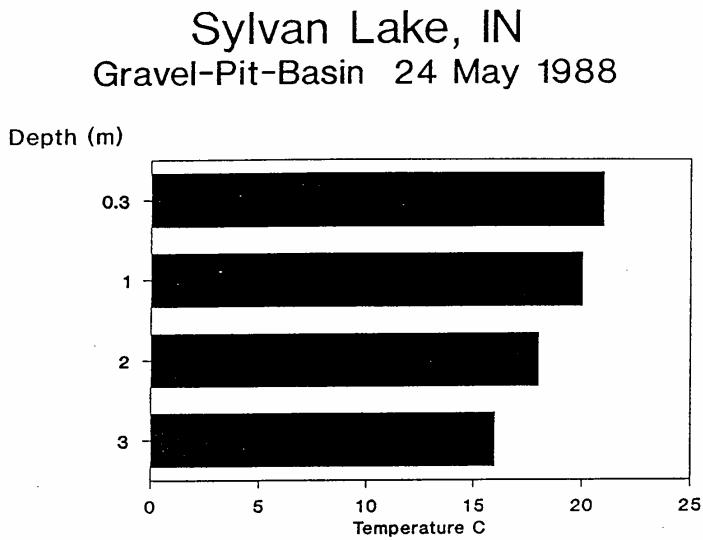
Phytoplankton samples were collected on 9 August 1988 using a Wisconsin plankton net (80 um mesh). Two types of tows were made at each site: one from the five-foot depth to the surface, and a second from the top of the thermocline to the surface. Samples were preserved with Lugol's solution in the field and transported to the laboratory for analysis. Phytoplankton counts utilized Sedgewick-Rafter cell with taxonomy based on keys in Standard Methods.

Physical/Chemical Parameters

Temperature. Water column profiles clearly demonstrated that all three basins (Gravel Pit, Cain, Lower) were displaying thermal stratification by the end of May 1988 (Figure 18) with the thermocline being between two and four meters depth. Of the three basins, Gravel Pit displayed the least pronounced stratification similarly to what was noted by Wetzel (1966) in 1963. Mean water column temperature in Cain basin was slightly lower than elsewhere in the lake possibly reflecting the greater depth of this basin. Stratification persisted in all three basins during August (Figure 19), but the thermocline moved deeper to 3-4 meters. As in May, stratification was least pronounced in Gravel Pit and mean water column temperature was lower in Cain.

Table 10. 1988 Physical/Chemical Parameter Values for Gravel Pit Basin (Gr.P.B.), Cain Basin (Cain B.), and Lower Basin (Low.B).

Sylvan Lake Waterchemistry	1988	May 24 Gr.P.B.	May 24 Cain B.	May 24 Low.B	August 9 Gr.P.B.	August 9 Cain B.	August 9 Low.B
Secchi	feet				1.3	3.6	2
Mean Dissolved Oxygen	mg/L	5.8	5.9	4.8	4.1	2.6	4.8
pH		7.8		7.4			
Ammonia	mg/L	0.14		0.29	0.29	0.18	0.7
Total Kjeldahl N	mg/L	0.86		0.78	1.35	0.86	1.43
Nitrate	mg/L	0.1		0.12	0.01	0.01	0.01
Nitrite	mg/L	0.02		0.02	0.01	0.01	0.01
Total Phosphorus	mg/L	0.06		0.04	0.14	0.07	0.18
Ortho Phosphorus	mg/L	0.06		0.02	0.08	0.05	0.07
N:P	atoms	41		66	26	33	27
Conductivity	umho/cm						
Alkalinity	mg/L	120					
Chlorophyll	mg/m3				59	95	15
Temperature	C	18.8	17.8	18.6	27.4	22.9	25



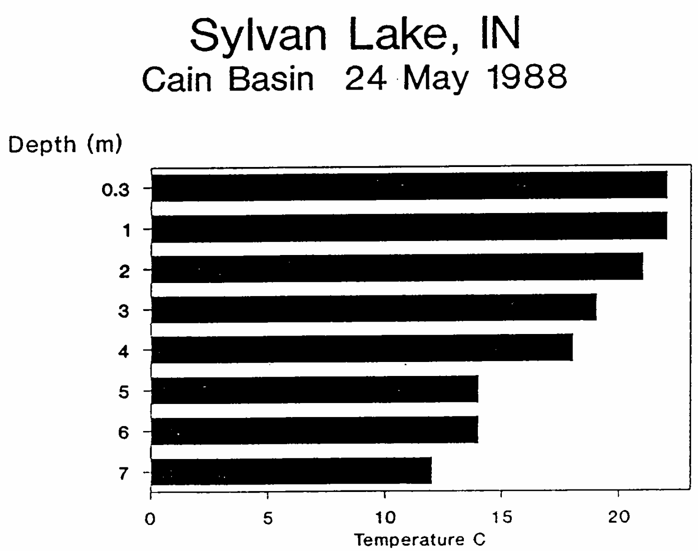
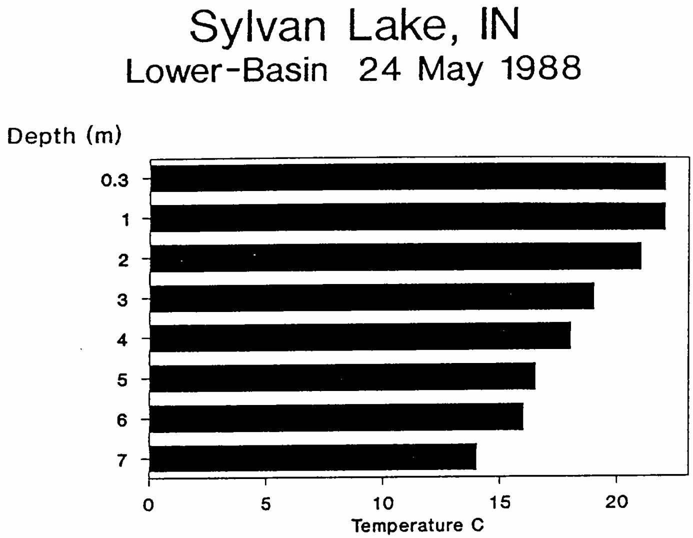


Figure 18. Temperature Profiles for Individual Basins of Sylvan Lake for May 1988.



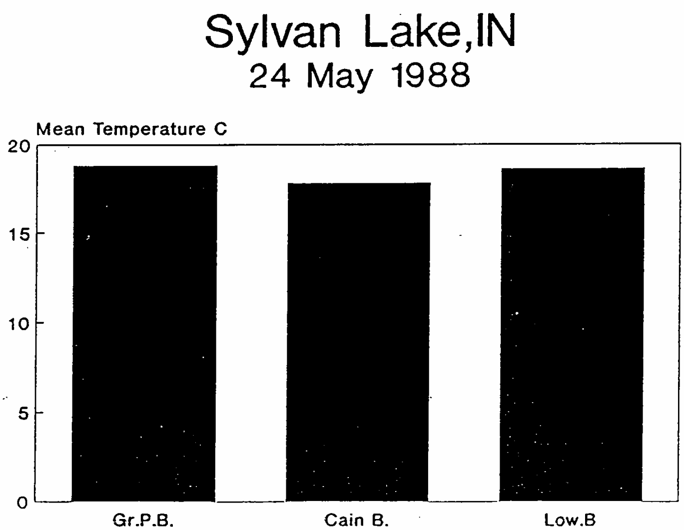
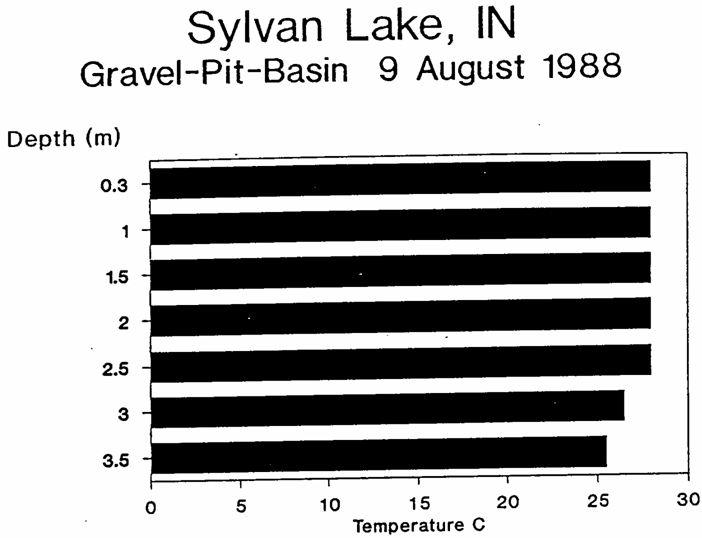


Figure 18. (Continued).



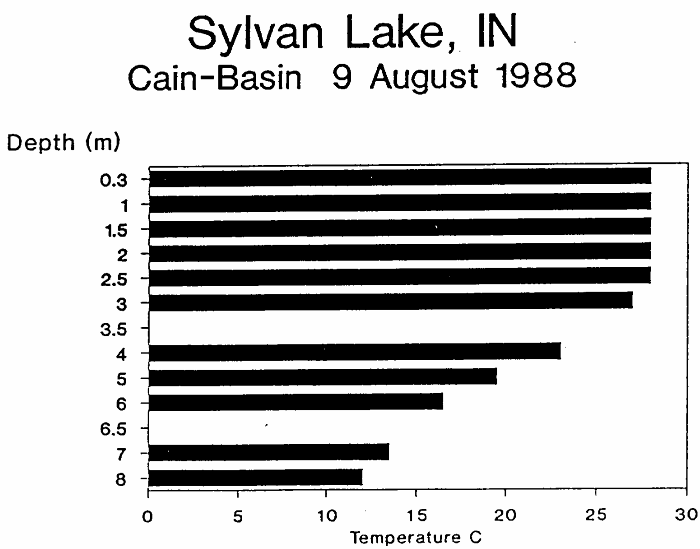
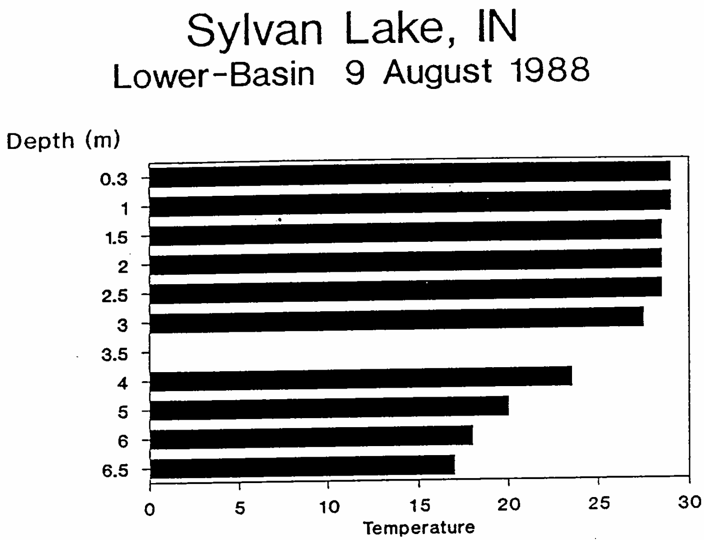


Figure 19. Temperature Profiles for Individual Basins of Sylvan Lake for August 1988.



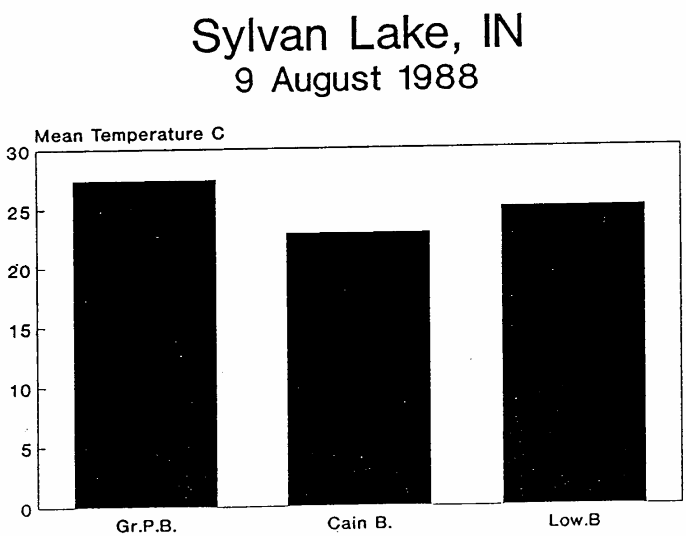


Figure 19. (Continued).

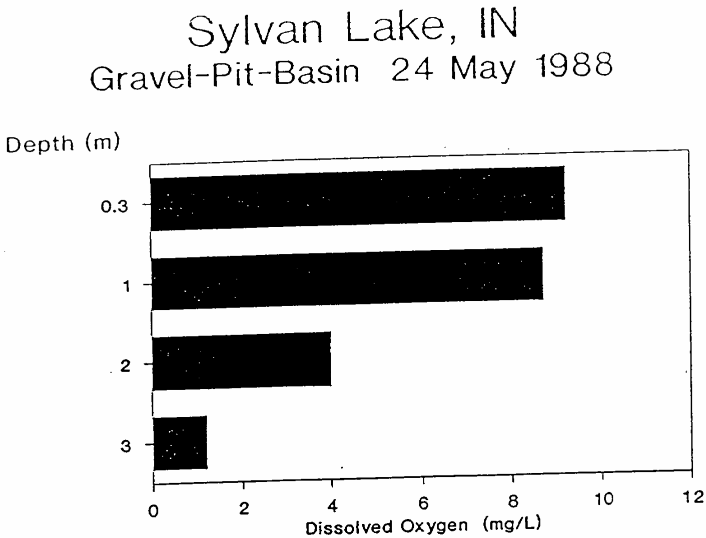
Temperature profiles for 1988 differed from both previous years as well as temperate lakes in general in being 2-3^{o}C higher than expected during August. Undoubtedly, this is a reflection of the extreme drought and temperature conditions of summer 1988 and should not be intrepreted as normal values.

Dissolved Oxygen. Midsummer oxygen values in the lower portion of the water column of lakes is governed by the degree of thermal stratification and the overall trophic state of the lake. The higher the trophic state (eutrophication) the greater the amount of organic matter falling to the bottom of the lake to decompose. If the lake is deep enough to stratify, oxygen is not replenished in the bottom layers readily and is consumed during the decomposition process. Thus, the higher the trophic state, the greater the likelihood that the lake becomes anoxic in the bottom of the water column (hypolimnion).

Pronounced water column deoxygenation was noted at all three sampling stations during May 1988 (Figure 20). As expected, the beginning of reduced oxygen corresponded to the bottom of the well mixed portion of the water column (epilimnion), the portion of the water column displaying the greatest temperature change per meter (thermocline). Although Gravel Pit and Cain remained oxygenated to some degree throughout their water columns, Lower basin was essential devoid of oxygen below 4 meters. When expressed as a mean for the entire water column, dissolved oxygen during May was lowest in Lower basin, with Gravel Pit and Cain basins displaying nearly identical values.

Deep water deoxygenation became more pronounced in August with all three basins being essentially anoxic below 2.5 meters (Figure 21). The basins ranked in order of decreasing mean water column oxygen values for August were: Lower, Gravel Pit, and Cain. All three basins displayed mean values less than 5 mg/L suggesting highly eutrophic conditions. On a lake average, mean water column dissolved oxygen concentrations declined between May and August 1988 (Figure 22). Progressive depletion of hypolimnetic oxygen concentrations throughout summer is a reflection of decomposition of phytoplankton settling out of the water column. Water column oxygen values undoubtedly decline sharply even in surface waters at nite in all basins of Sylvan Lake when algae are no longer photosynthetic. Mean water column values for 1988 were within the range of previous surveys since 1967 (Table 3).

Historically, Sylvan Lake has displayed severe deoxygenation of the water column below 10-15 feet depth as early as June (Table 4). Although only one date was available for comparison, 1963 did not display the pronounced deoxygenation of the water column noted during



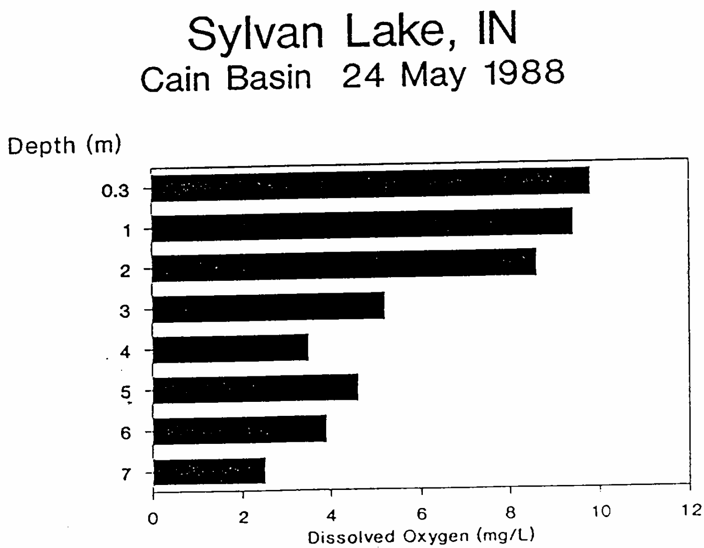
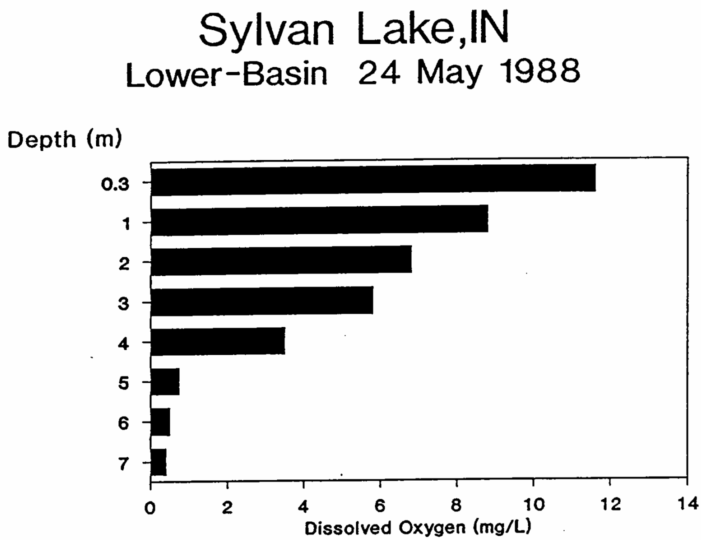


Figure 20. Dissolved Oxygen Profiles for Individual Basins of Sylvan Lake for May 1988.



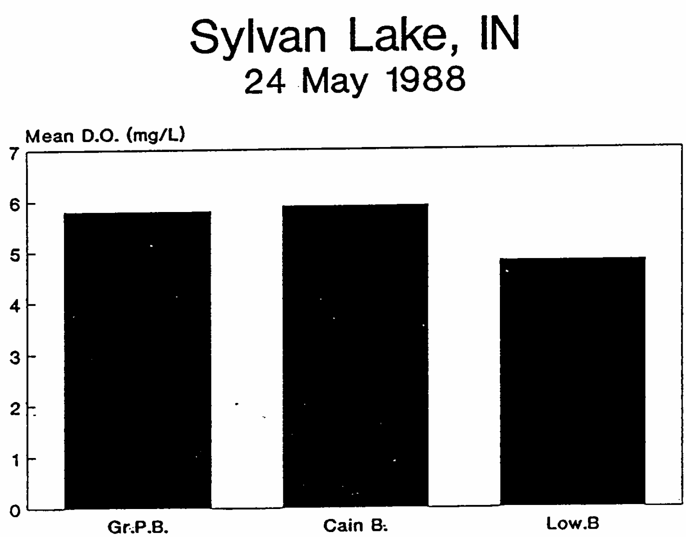
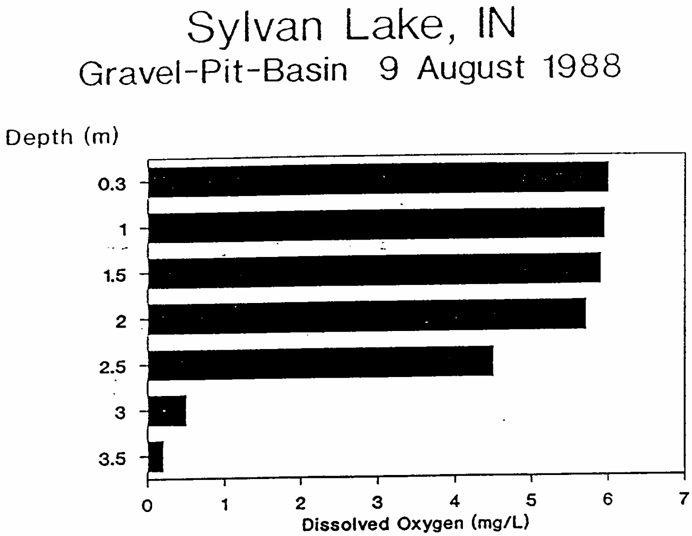


Figure 20. (Continued).



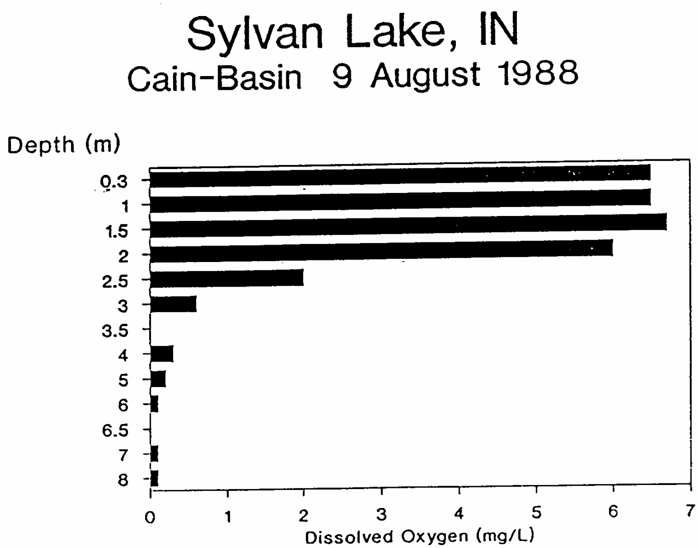
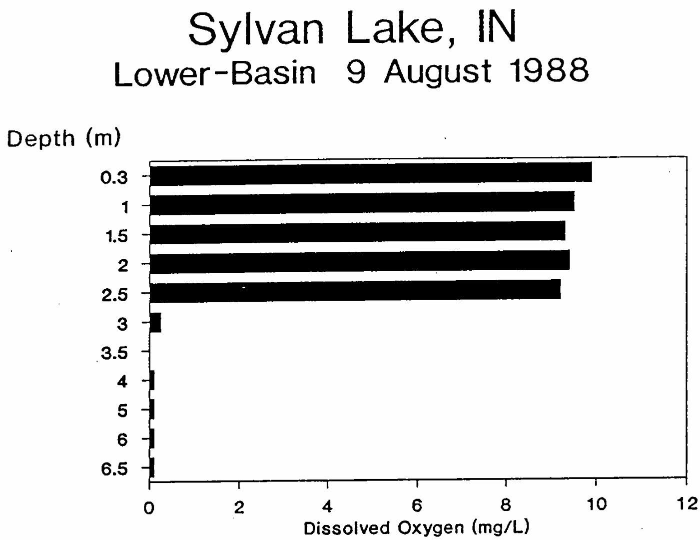


Figure 21. Dissolved Oxygen Profiles for Individual Basins of Sylvan Lake for August 1988.



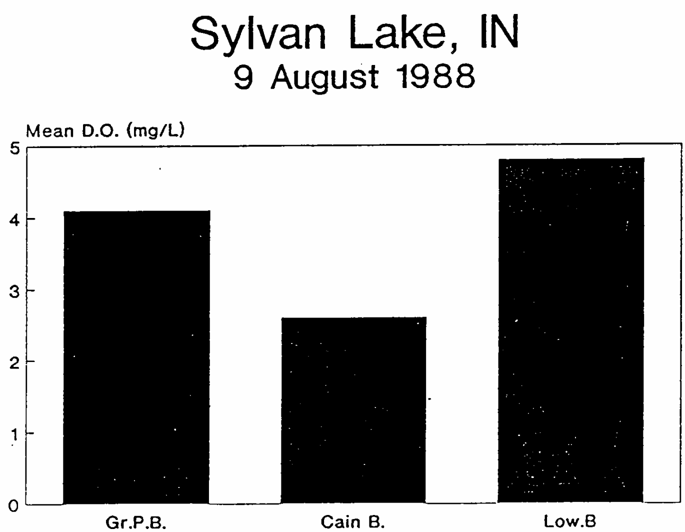


Figure 21. (Continued).

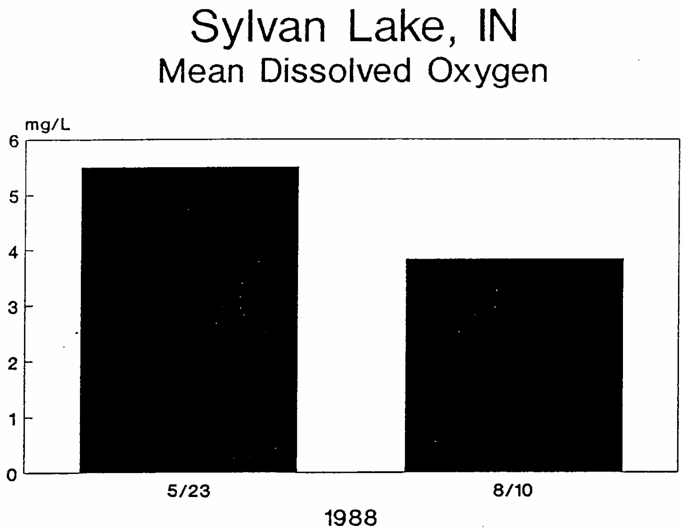


Figure 22. Mean Dissolved Oxygen for Sylvan Lake During May and August 1988.

1988. In addition, the depth to anoxia (8 feet) during August 1988 was shallower than reported for the three years for which this month was sampled (1963, 1976, 1986). While it is possible that midsummer oxygen depletion may have increased recently in Sylvan Lake, it is not known how much this is influenced by the extreme temperature and drought conditions of 1988.

Secchi Disc Transparency. As stated earlier in this report, the depth that a Secchi disc can no longer be seen in a water column is indicative of the amount of algae suspended in the water column to block light transmission. Thus, the shallower the Secchi depth during midsummer, the more productive (eutrophic) a lake is presumed to be. Secchi transparency was measured only once (9 August) during 1988 at the three sampling stations (Figure 23). Water was clearest in Cain basin (3.6 feet) followed by Lower basin (2.0 feet) and Gravel Pit basin (1.3 feet). The 1988 values correspond well with the 2.8 feet mean for Sylvan Lake calculated for the comparable August date in 1987 (Figure 4). In general, the Secchi data for 1988 follow the trend towards increased transparency in Sylvan Lake since 1985 (Figure 5).

Ammonia. The maximum ammonia concentration recorded during the 1988 survey for both May and August was for Lower basin (Figure 24). Although Cain basin was not sampled during May, Gravel Pit basin was lower at 0.14 mg/L. Ammonia increased in all three basins during August with basins ranked in order of decreasing values as Lower, Gravel Pit, and Cain. Mean ammonia values for Sylvan Lake during May (0.21 mg/L) and August (0.37 mg/L) were comparable those reported for the lake since at least 1973 (Table 3).

Nitrite-Nitrate. Nitrite nitrogen concentrations were identical at all sampling sites during both May and August 1988 (Figure 26) with the former month being greater, 0.02 versus 0.01 mg/L (Figure 27). Nitrate values were an order of magnitude greater than nitrite in the two basins sampled during May but were approximately equal to nitrite during August (Figure 28). Maximum nitrate concentrations were recorded in Lower basin during May, while no interbasin differences were noted during August. The 1988 mean values (Figure 29) were lower than reported from 1961 to 1967 (Table 3). Unfortunately, these were the last dates for which data were available.

Kjeldahl Nitrogen. While May Kjeldahl nitrogen values were lower in the two basins sampled, values were roughly comparable between Gravel Pit and Lower basins during both months (Figure 30). Cain basin was sampled only during August and its value was approximately that found in the other two basins during May. Mean Kjeldahl values for both

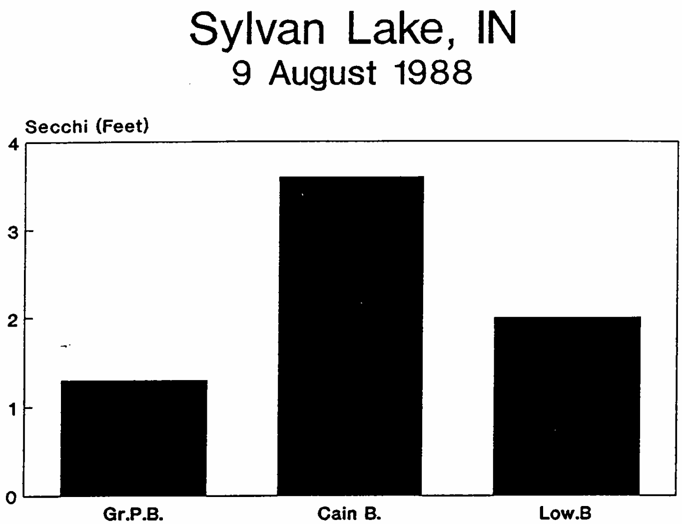
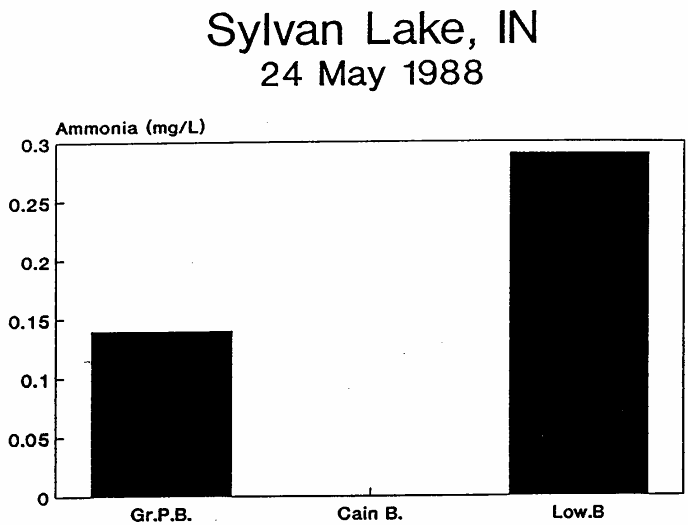


Figure 23. Secchi Transparency for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During August 1988.



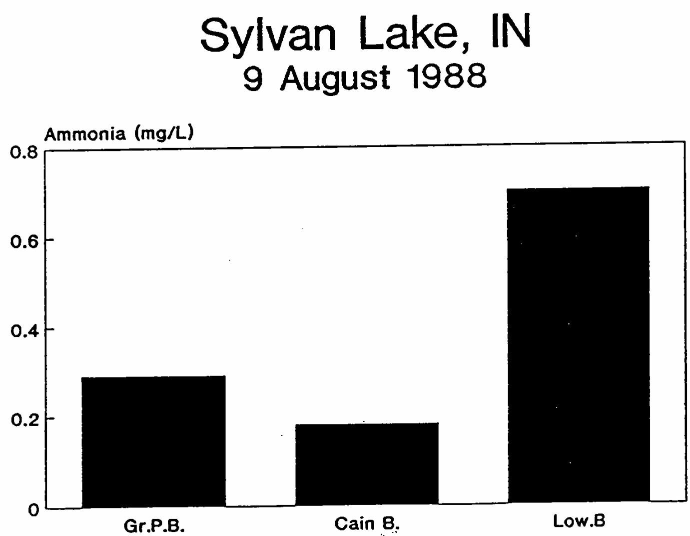


Figure 24. Ammonia Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

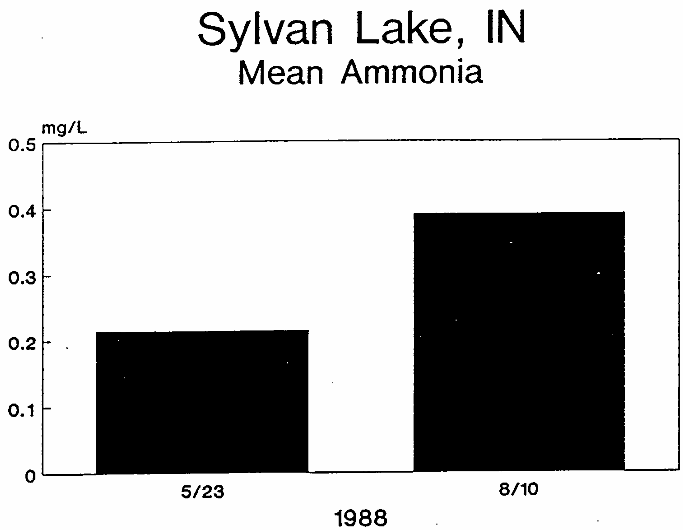
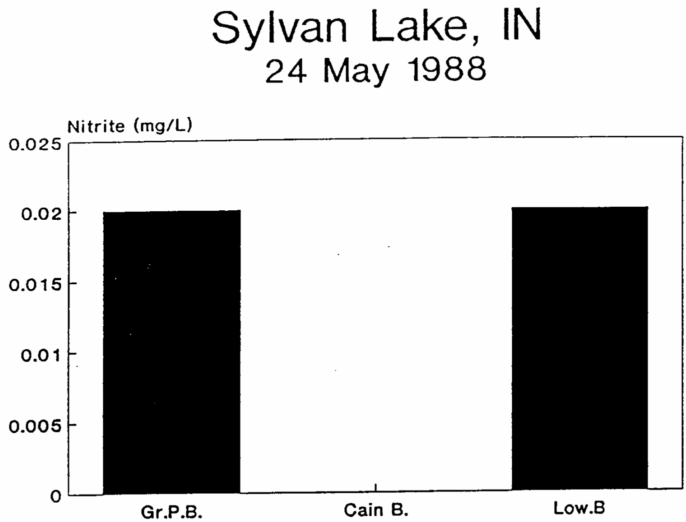


Figure 25. Mean Ammonia Concentrations in Sylvan Lake During May and August 1988.



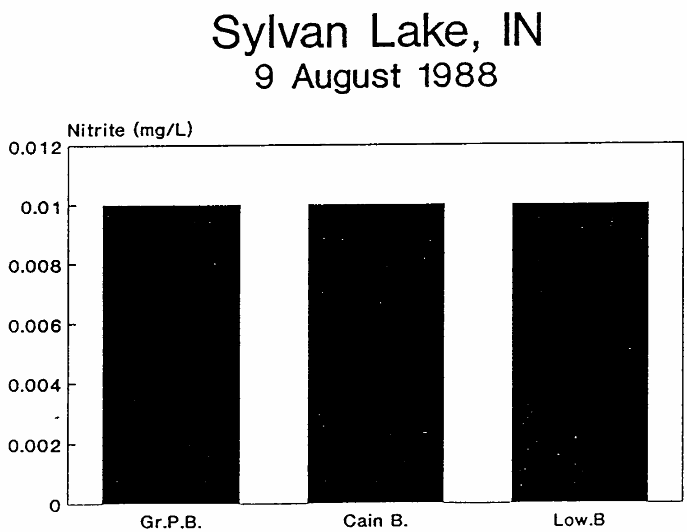


Figure 26. Nitrite Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

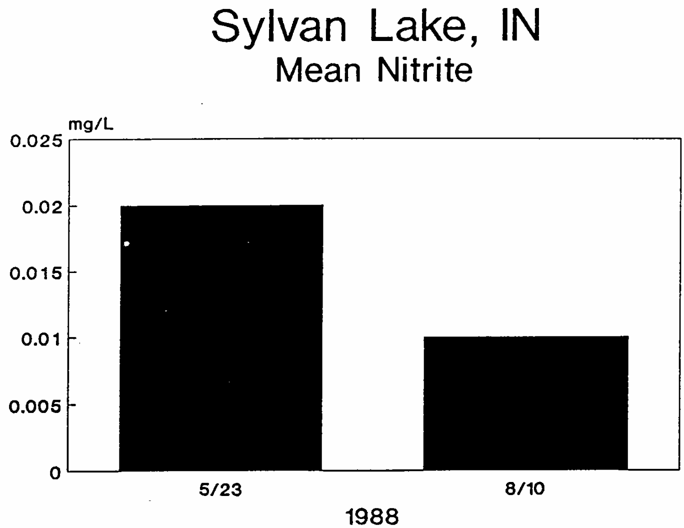
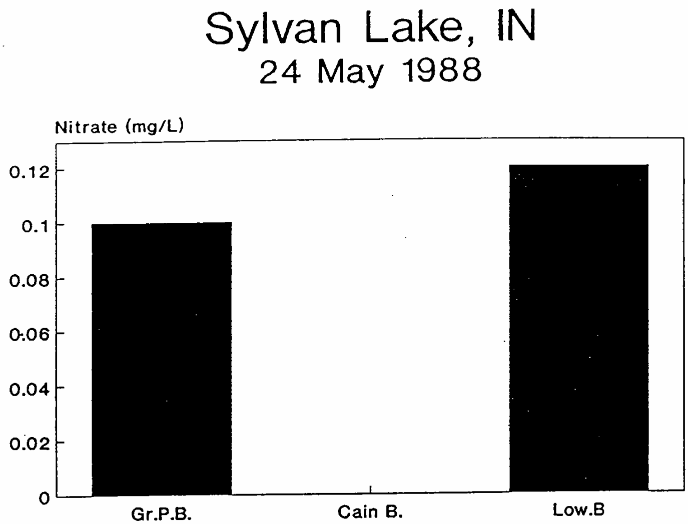


Figure 27. Mean Nitrite Concentrations in Sylvan Lake During May and August 1988.



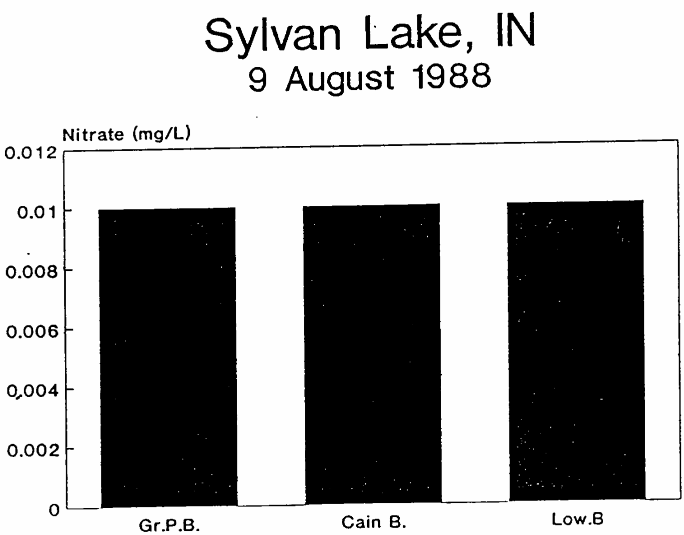


Figure 28. Nitrate Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

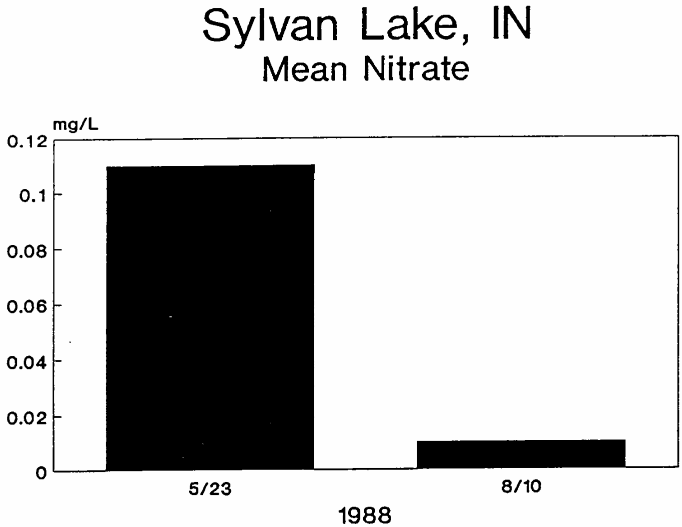
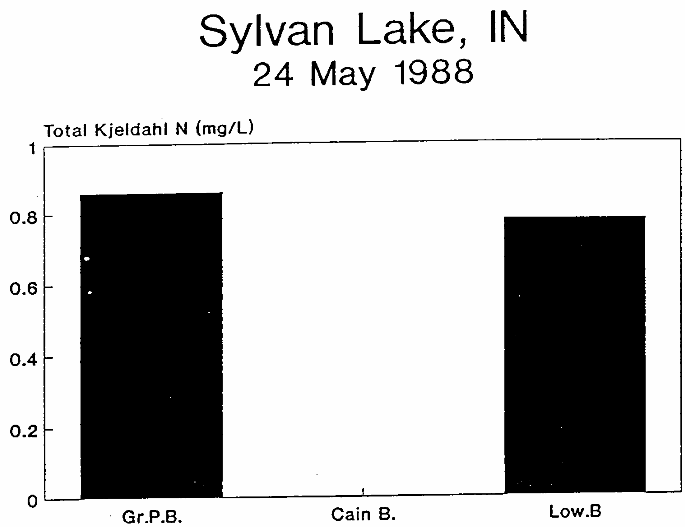


Figure 29. Mean Nitrate Concentrations in Sylvan Lake During May and August 1988.



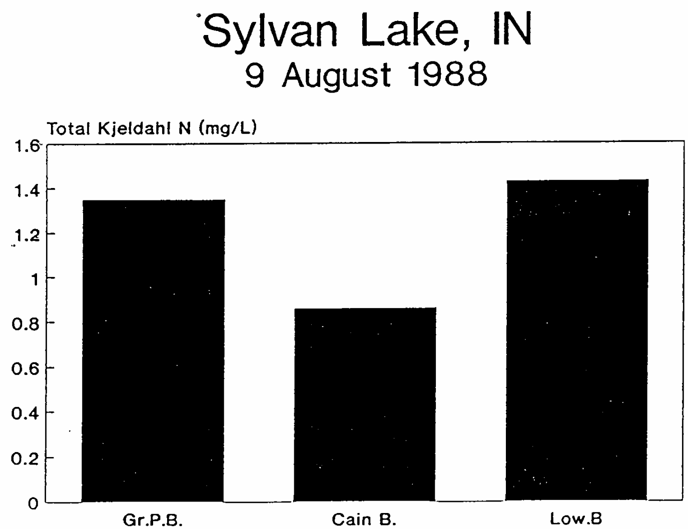


Figure 30. Kjeldahl Nitrogen Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

months (0.81 and 1.2 mg/L) were lower than the only historical values (2.16 mg/L in 1973 and 1.4 mg/L in 1976) for this parameter (Figure 31).

Total Phosphorus. Of the two basins sampled, Gravel Pit basin displayed the greater total phosphorus during May (Figure 32). Concentrations in both Gravel Pit and Lower basins decreased by August, while Cain basin was approximately at levels seen in the other basins during May. Mean total phosphorus values for Sylvan lake during May (0.05 mg/L) and August (0.13 mg/L) 1988 (Figure 33) were similar to values (0.07-0.17 mg/L) reported for 1973-1987, but were markedly lower than the 0.8-5.5 mg/L levels seen during the 1961-1967 period (Table 3).

Ortho Phosphorus. As noted for total phosphorus ortho phosphorus concentrations were greater in Gravel Pit than Lower basin during both May and August 1988 (Figure 34). Values in both basins increased during August and were greater than those of Cain basin. The mean ortho phosphorus value for Sylvan Lake for May (0.04 mg/L) and August (0.65 mg/L) were comparable to that of 1973, the only other time that ortho phosphorus was measured (Table 3).

Nitrogen:Phosphorus Ratios. The ratio of total nitrogen to total phosphorus can be useful in delineating which of these two essential nutrients are limiting primary production in lakes. Numerous authors (Baker et al. 1981, Kratzer and Brezonik 1981, Canfield 1983) have proposed that N:P ratos less than 10 suggest nitrogen limitation, while those greater than 10 suggest phosphorus. The N:P ratios in Gravel Pit and Lower basins exceeded 40 during May suggesting that both were phosphorus limited (Figure 36). Ratios declined during August but still exceeded 25 in all three basins sampled suggesting that these basins were approaching nitrogen limitation as the summer progressed, and algae were actively utilizing the available phosphorus pool. Mean ratio values for Sylvan Lake for 1988 were 54 in May and 28 in August (Figure 37).

pH. This parameter was measured only during May and only for Gravel Pit (7.8) and Lower (7.4) basins (Table 10). These values are within the range reported in previous surveys (Table 3).

Alkalinity. Alkalinity was only measured during May 1988 and only for Gravel Pit basin (Table 10). The 120 mg/L reported is comparable to values reported for Sylvan Lake since at least 1979 (Figure 9).

Chlorophyll. Chlorophyll is a good estimator of algal biomass in a lake. Chlorophyll concentrations were measured only during August 1988 (Figure 38). The three basins were ranked in order of decreasing chlorophyll values as Cain (95

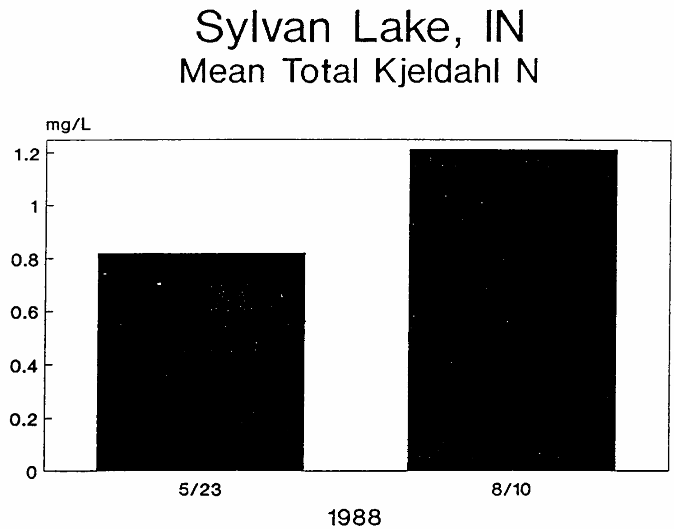
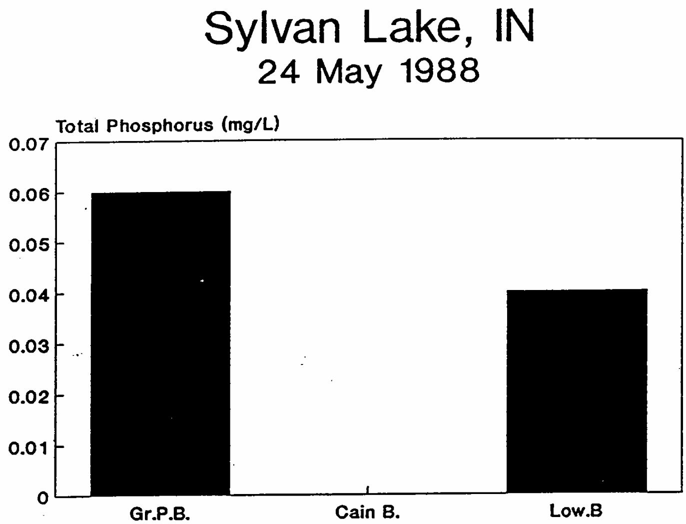


Figure 31. Mean Kjeldahl Nitrogen Concentrations in Sylvan Lake During May and August 1988.



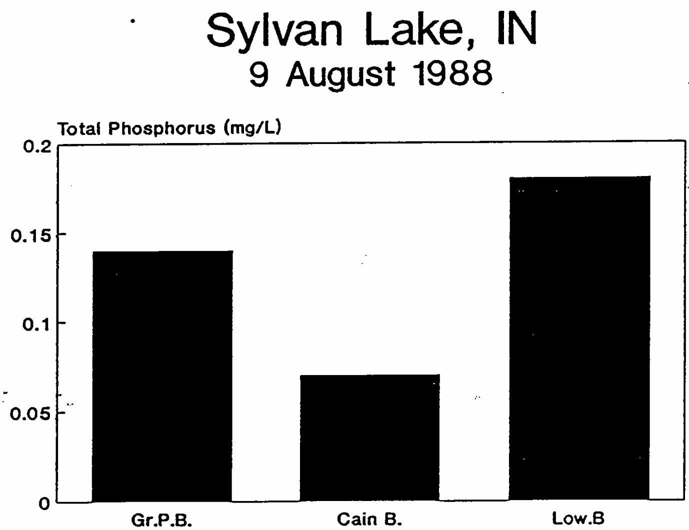


Figure 32. Total Phosphorus Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

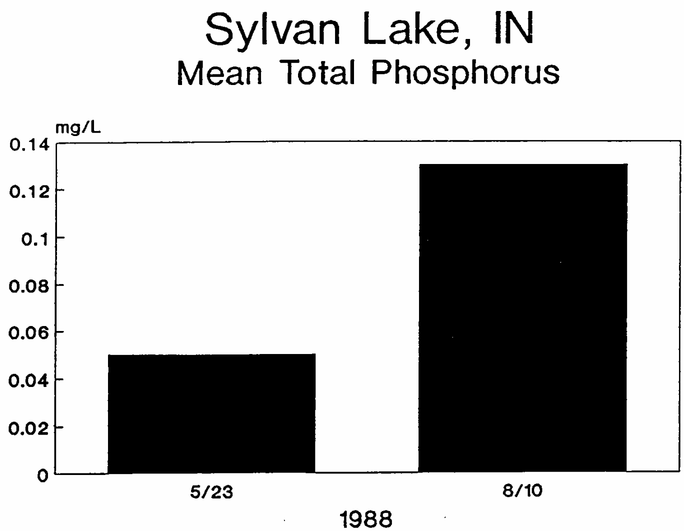
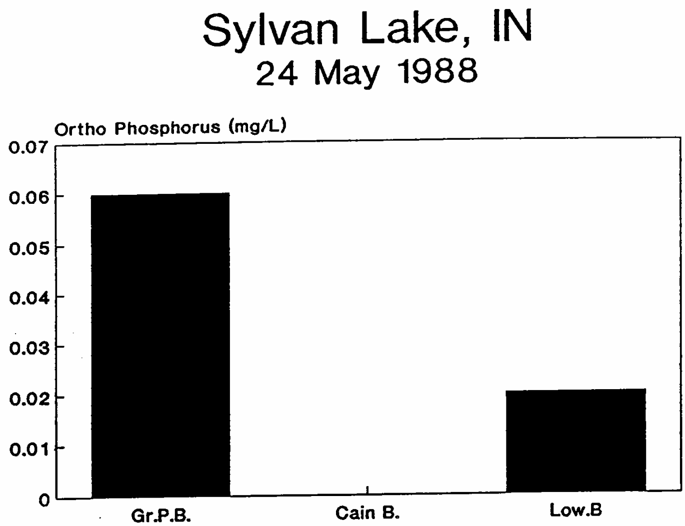


Figure 33. Mean Total Phosphorus Concentrations in Sylvan Lake During May and August 1988.



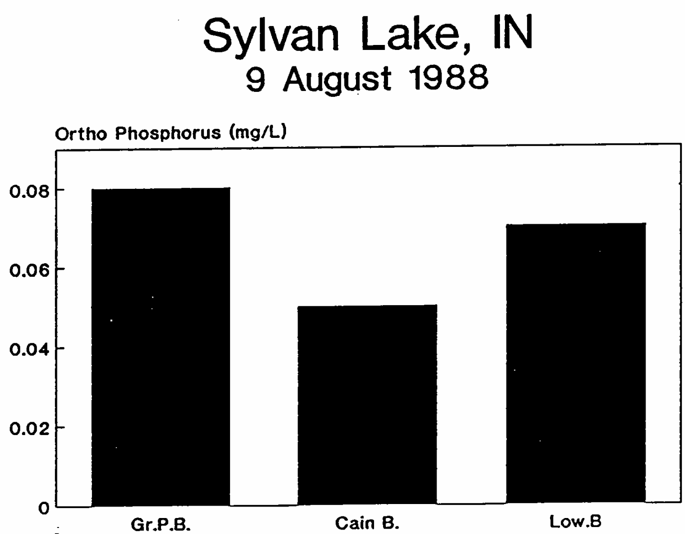


Figure 34. Ortho Phosphorus Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

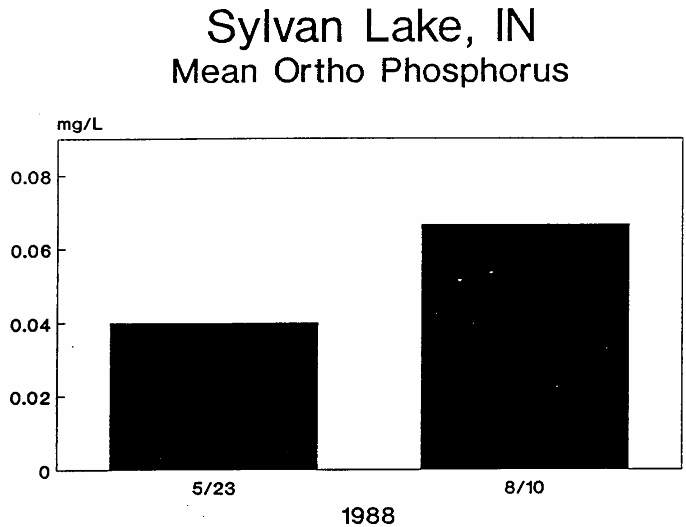


Figure 35. Mean Ortho Phosphorus Concentrations in Sylvan Lake During May and August 1988.

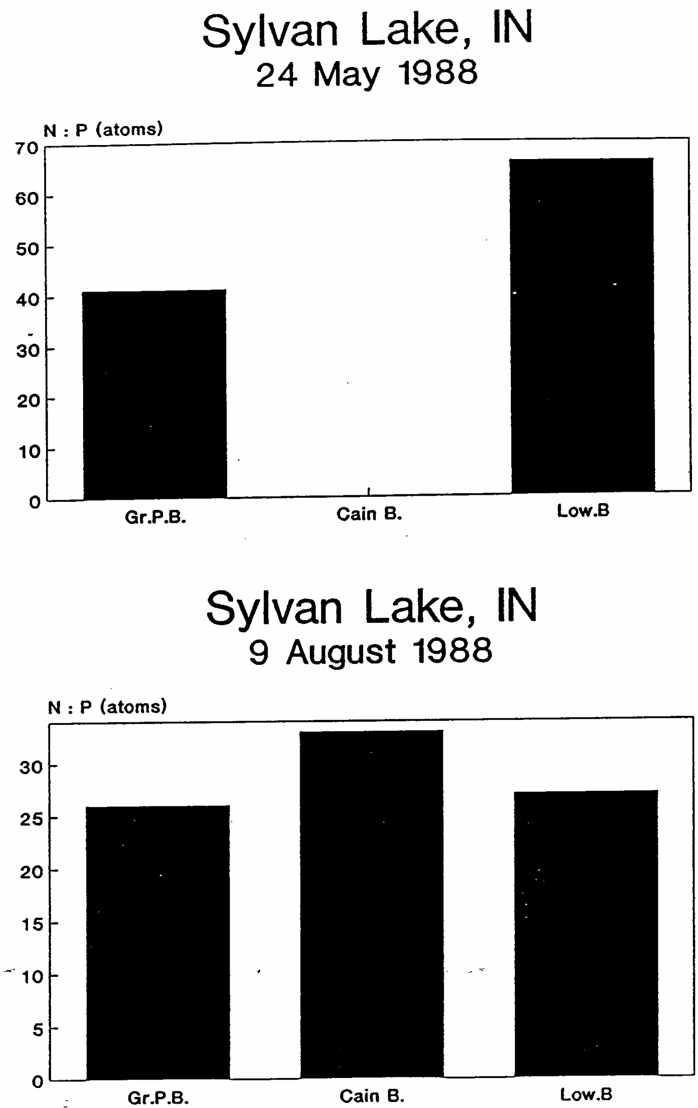


Figure 36. Nitrogen to Phosphorus Ratios for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During May and August 1988.

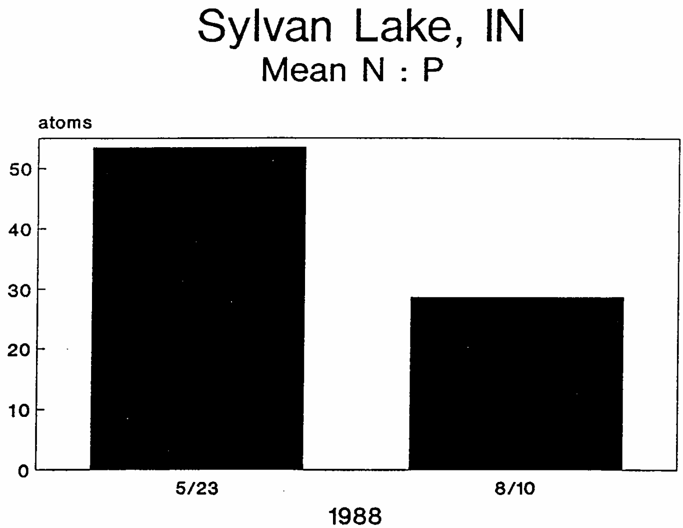


Figure 37. Mean Nitrogen to Phosphorus Ratios in Sylvan Lake During May and August 1988.

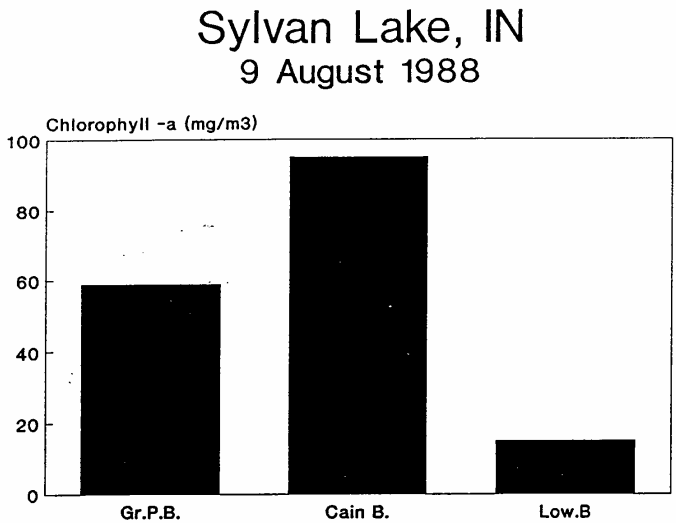


Figure 38. Chlorophyll A Concentrations for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake During August 1988.

mg/L), Gravel Pit (59 mg/m^3), and Lower (15 mg/m^3). The range of values were comparable to that reported for 1973 and 1976.

ISBH Trophic State Index

Mr Harold BonHomme of the Indiana State Board of Health devised a eutrophication index specific to Indiana lakes based on summertime sampling of 307 lakes in the mid 1970's. Parameters included in the index construction were phosphorus, nitrogen forms, dissolved oxygen, light penetration and transmission, and phytoplankton abundance and group dominance. Ranges for each parameter were assigned eutrophy points, and the final eutrophication index value for a given lake represented the sum of eutrophy points from all parameters combined.

The 1975 eutrophication index for Sylvan Lake was calculated by the Indiana State Board of Health as 62, thus assigning the lake to the category of worst water quality, Class Three. Parameters for the 1988 index calculation were identical to those used for the 1975 index with the exception of light penetration, which was measured with a photocell in 1975 and was approximated in 1988 by multiplying the Secchi disc reading by 2.5. The latter is considered a crude estimate of the 1% light level and is not directly comparable to calculations based directly from photocells. The eutrophication indices (calculations in Tables 11-13) for Gravel Pit (34), Cain (31) and Lower (36) basins based on data collected in August 1988 were markedly lower than reported for 1975 and are characteristic of lakes (indices 26-50) in the category of intermediate eutrophic conditions (Class Two). While suggestive of a reduction in trophic state since 1975, such an interpretation must be approached cautiously. The 1988 database was extremely sparse and conditions of that year may not be broadly representative of current conditions because of the extreme heat and drought occuring during the sampling period. The phytoplankton assemblage continues to be dominated numerically by blue-green algae with Anacystis, Lyngbya and Anabaena as the principal genera. Additional monitoring of the parameters needed for index construction is needed in order to validate whether trophic state has in fact declined recently.

Stream Chemistry

Two streams were sampled during the 1988 survey (Figure 1). Henderson Lake Ditch drains the eastern-southeastern section of the watershed including outflow from Bixler, Henderson, Beck, Halt, Round and Little Long Lakes. The latter two lakes drain first into Waterhouse Ditch before

Table 11. 1988 IDEM Index Calculations for Gravel Pit Basin.

ISBH LAKE EUTROPHICATION INDEX----------Sylvan Lake-Gravel Pit Basin

	Parameter	Measured Value (units)	Eutrophy Points
I.	Total Phosphorus	0.14 ppm	3
II.	Soluble Phosphorus	0.08 ppm	3
III.	Organic Nitrogen	1.35 ppm	3
IV.	Nitrate	<.01 ppm	0
V.	Ammonia	0.29 ppm	0
VI.	Dissolved Oxygen Saturation at five feet from surface	77 %	0
VII.	Dissolved Oxygen (% measured water column with >0.1 ppm DO)	100 %	0
VIII.	Light Penetration (Secchi Disk)	1.3 feet	6
IX.	Light Transmision (Depth of 1% transmittance)	3.28 feet	4
X.	Total Plankton		
X(a).	Vertical tow, 5 ft to surface	2179 cells/mL	3
	Blue-green dominance?	Yes	5
X(b).	Vertical tow, thermocline to surface	2728 cells/mL	2
	Blue-green dominance?	Yes	5
		LEI =	34

Table 12. 1988 IDEM Index Calculations for Cain Basin.

ISBH LAKE EUTROPHICATION INDEX---------Sylvan Lake-Cain Basin

	Parameter	Measured Value (units)	Eutrophy Points
I.	Total Phosphorus	0.07 ppm	3
II.	Soluble Phosphorus	0.05 ppm	2
III.	Organic Nitrogen	0.86 ppm	3
IV.	Nitrate	<.01 ppm	0
V.	Ammonia	0.18 ppm	0
VI.	Dissolved Oxygen Saturation at five feet from surface	87 %	0
VII.	Dissolved Oxygen (% measured water column with >0.1 ppm DO)	75 %	1
VIII.	Light Penetration (Secchi Disk)	3.6 feet	6
IX.	Light Transmision (Depth of 1% transmittance)	9.02 ft	4
X.	Total Plankton		
X(a).	Vertical tow, 5 ft to surface	1574 cells/mL	2
	Blue-green dominance?	Yes	5
X(b).	Vertical tow, thermocline to surface	841 cells/mL	0
	Blue-green dominance?	Yes	5
		LEI=	31

Table 13. 1988 IDEM Index Calculations for Lower Basin.

ISBH LAKE EUTROPHICATION INDEX---------Sylvan Lake-Lower Basin

	Parameter	Measured Value (units)	Eutrophy Points
I.	Total Phosphorus	0.13 ppm	3
II.	Soluble Phosphorus	0.04 ppm	2
III.	Organic Nitrogen	1.17 ppm	3
IV.	Nitrate	<.01 ppm	0
V.	Ammonia	0.42 ppm	2
VI.	Dissolved Oxygen Saturation at five feet from surface	122 %	2
VII.	Dissolved Oxygen (% measured water column with >0.1 ppm DO)	62 %	2
VIII.	Light Penetration (Secchi Disk)	2.0 feet	6
IX.	Light Transmision (Depth of 1% transmittance)	4.92 feet	4
X.	Total Plankton		
X(a).	Vertical tow, 5 ft to surface	1567 cells/mL	2
	Blue-green dominance?	Yes	5
X(b).	Vertical tow, thermocline to surface	914 cells/mL	0
	Blue-green dominance?	Yes	5
		LEI=	36

joining Henderson Lake Ditch. Henderson Lake historically has been the sewage outfall for the town of Kendallville. Total area for the Henderson Ditch segment of the Sylvan Lake watershed is 2833 acres. Approximately 87% of its drainage is devoted to pasture and row crops, with wetlands and forests together only comprising 11%. Henderson Lake Ditch enters Sylvan Lake at the eastern end of Gravel Pit basin, a shallow area displaying extremely dense macrophyte growth. This stream was sampled at two sites: County Roads 850 N and 660 E.

The second stream, Waterhouse Ditch is a subset of the Henderson Lake Ditch watershed and joins the latter before entering Sylvan Lake. This stream drains an area of 946 acres including Round and Little Long Lakes. Rowcrops and pasture comprised 79% of the watershed with urban and forest being only 10% and 3%, respectively. This stream was sampled just upstream of its junction with Henderson Lake Ditch.

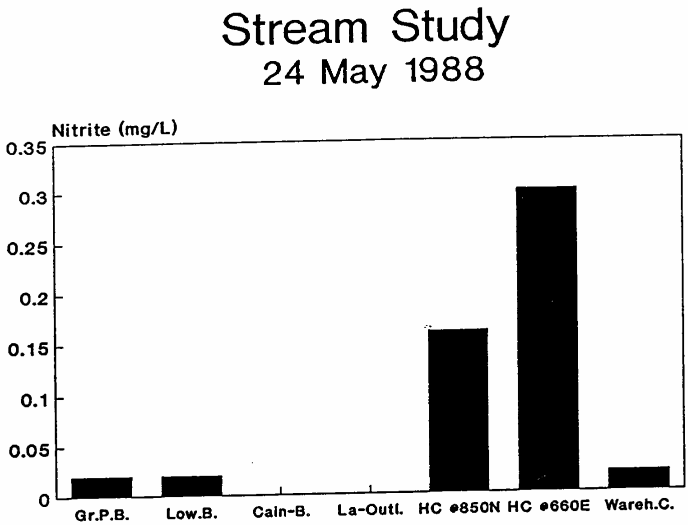
Water chemistry data for Henderson Lake Ditch and Waterhouse Ditch were collected twice during 1988: 24 May and 9 August. Concurrent samples were collected in Gravel Pit and Lower basins during May and Gravel Pit, Cain, Lower basins as well as the late outlet during August. Stream data were also supposed to be collected during storm events, but because of the extreme drought of 1988, no events were sampled. The following discussion compares stream water chemistry with that of lake and outlet stations for individual sampling dates.

Nitrite concentrations in Henderson Lake Ditch (0.16-0.39 mg/L) were at least ten times greater than in Waterhouse Ditch or any lake station during both May and August (Figure 39). On both sampling dates, however, little difference was noted among the latter stations (0.01-0.02 mg/L)

As noted for nitrite, nitrate concentrations for Henderson Lake Ditch greatly exceeded those of either the lakes or the Waterhouse Ditch station during May and August 1988 (Figure 40). Values did decline at all sites between May and August. Waterhouse Ditch concentrations were greater than any lake station during May but roughly comparable during August.

With the exception of the 850 N station during August, ammonia values at Henderson Ditch stations always were greater than other sampling stations (Figure 41). Lake stations were ranked in order of decreasing ammonia values as Lower, Gravel Pit, and Cain basins, with Lower basin always having greater values than Waterhouse Ditch.

As noted for ammonia, Kjeldahl nitrogen values were always greater than other stations with the exception of the



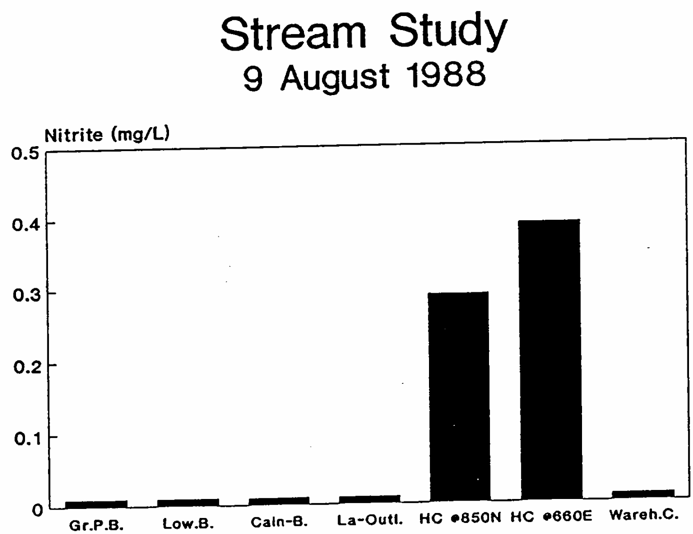
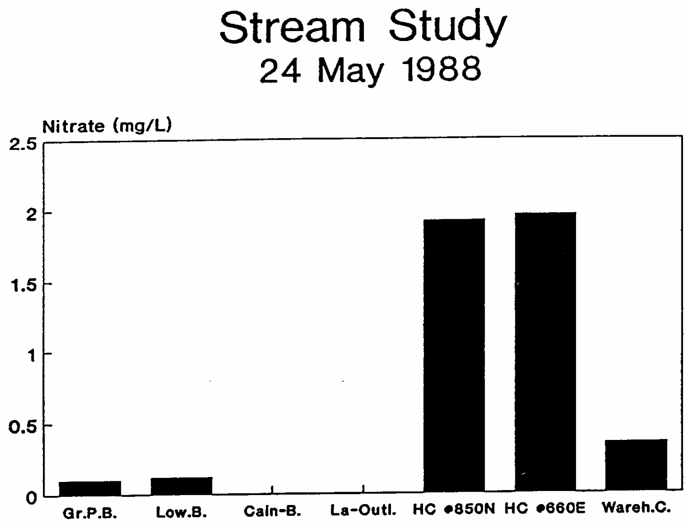


Figure 39. Nitrite Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



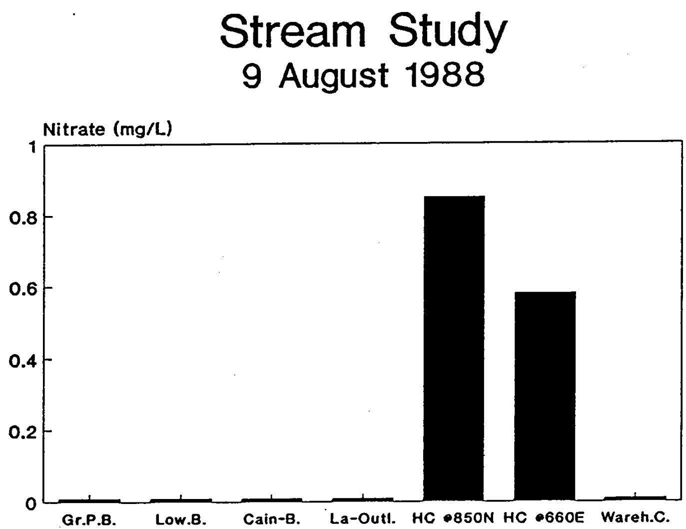
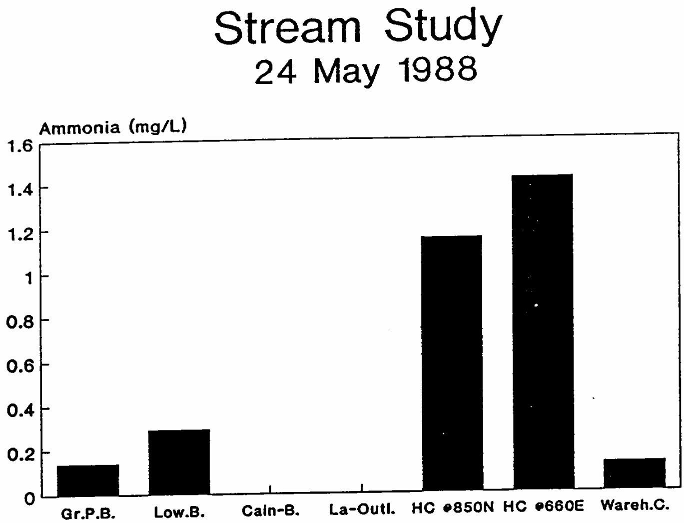


Figure 40. Nitrate Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



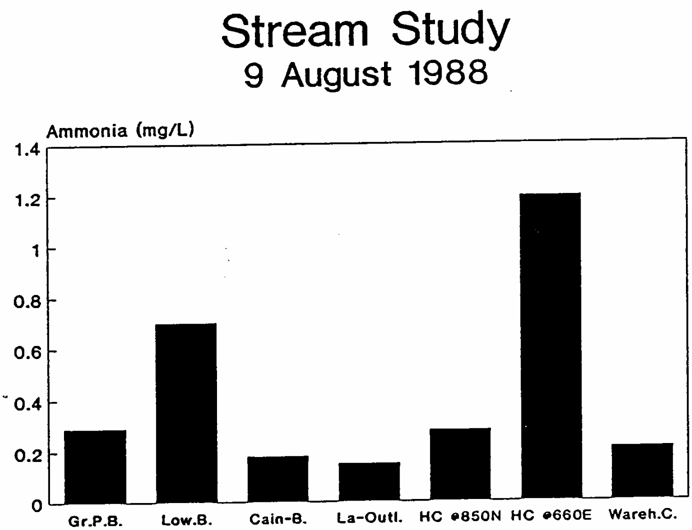


Figure 41. Ammonia Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.

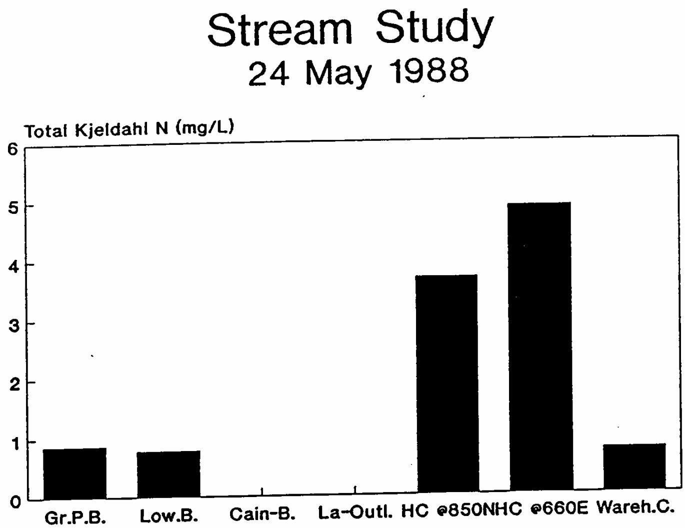
850 N station during August (Figure 42). Waterhouse Ditch concentrations never exceeded any lake station value and during August were considerable lower. Although detailed data are lacking for May, TKN values in Gravel Pit and Lower basins were almost double those of Cain basin and the lake outlet.

The lowest total phosphorus value of any stream site during May and August 1988 was for Waterhouse Ditch (Figure 43). As with the nitrogen parameters, both Henderson Lake Ditch sites displayed the greatest total phosphorus during both months with the exception of the 850 N site during August. While Gravel Pit was greater than Lower basin during May, the basins ranked in order of decreasing total phosphorus values during August were Lower, Gravel Pit, Cain with the lowest value found at the lake outlet. On both sampling dates, all lake sites were greater than Waterhouse Ditch. Finally, in August, concentrations at both Gravel Pit and Lower basin exceeded that of the 850 N site of Henderson Lake Ditch.

Orthophosphorus values for Henderson Lake Ditch exceeded those of Waterhouse Ditch and all lake stations during both May and August (Figure 44). A general reduction in concentrations westward through Sylvan Lake was noted during both May and August with the basins ranked in order of decreasing values as Gravel Pit, Lower, Cain and the outlet with the lowest value. It appears that Sylvan Lake is actively trapping phosphorus being delivered from the watershed in spite of its relatively rapid (6 month) flushing time.

As mentioned previously in this report, the ratio of total nitrogen to total phosphorus can be useful in delineating which of these two essential nutrients is limiting photosynthetic activity (algae or macrophytes) in aquatic systems. Such ratios were calculated for both the May and August data (Figure 45). All stations were characterized by N:P ratios greater than 40 during May and 20 during August, suggesting that phosphorus is the most likely nutrient limiting photosynthetic activity. It is interesting to note, however, that N:P ratios decreased progressively from east to west in Sylvan Lake.

Total suspended solids were greatest at the 850 N station of Henderson Lake Ditch during both May (61 mg/L) and August (25 mg/L) 1988 (Figure 46). It is interesting to note that unlike most chemical parameters just described, total suspended solids were greater at 850 N than at 660 E on Henderson Lake Ditch. With the exception of Gravel Pit and Lower basins during August, TSS values for Waterhouse Ditch were greater than at any lake station during both months. Within the lake, TSS increased toward the outlet during both months likely as a result of the buildup of



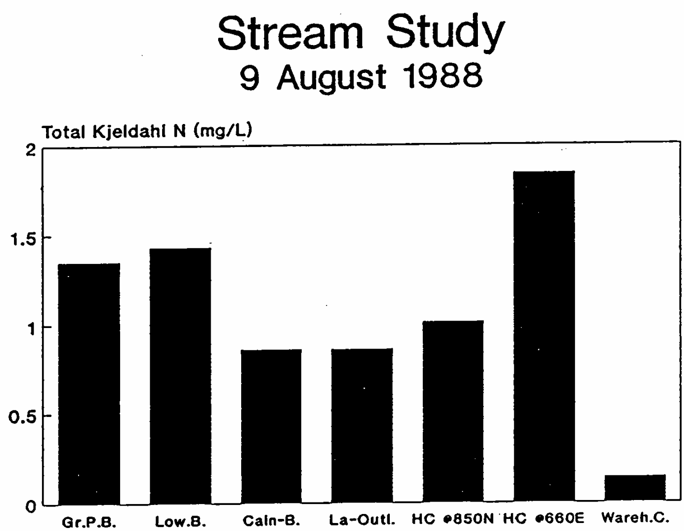
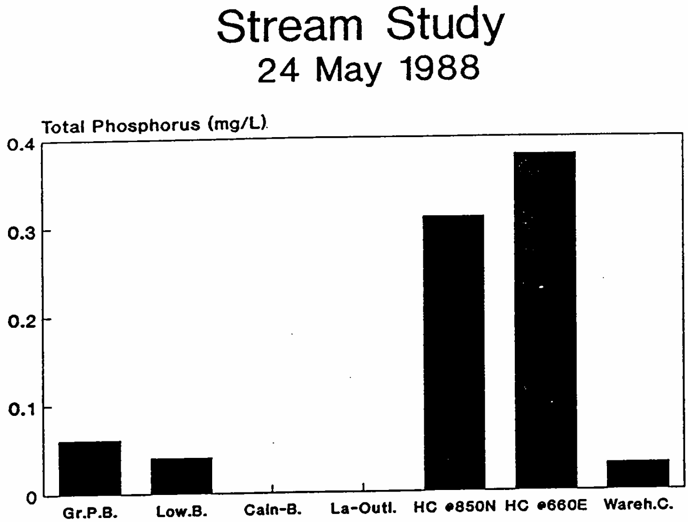


Figure 42. Total Kjeldahl Nitrogen Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La - Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



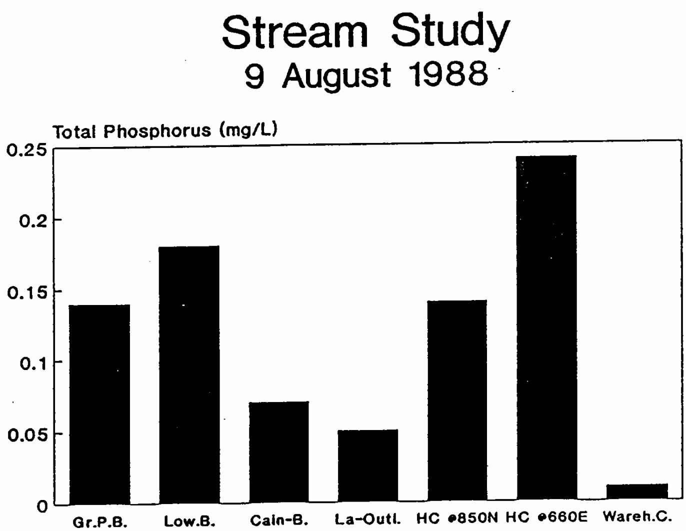
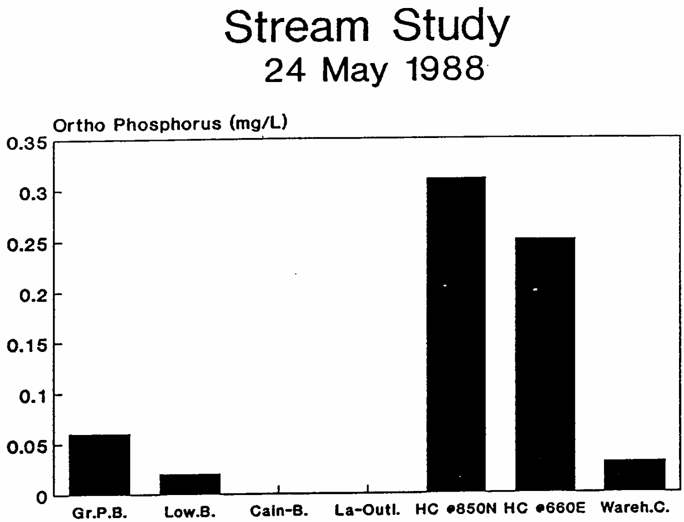


Figure 43. Total Phosphorus Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



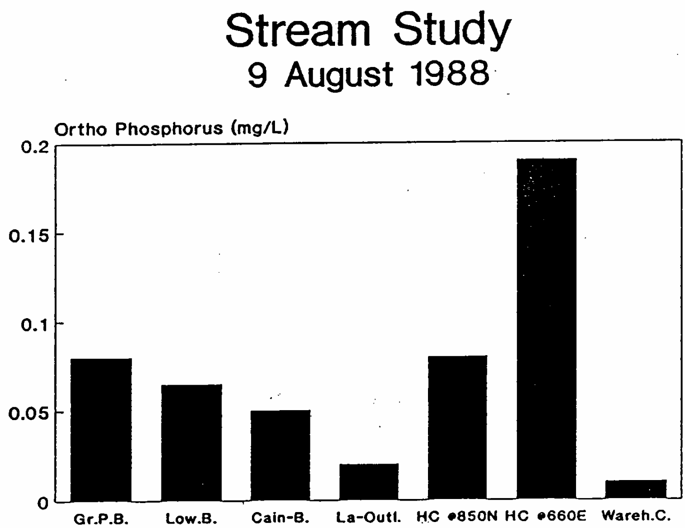
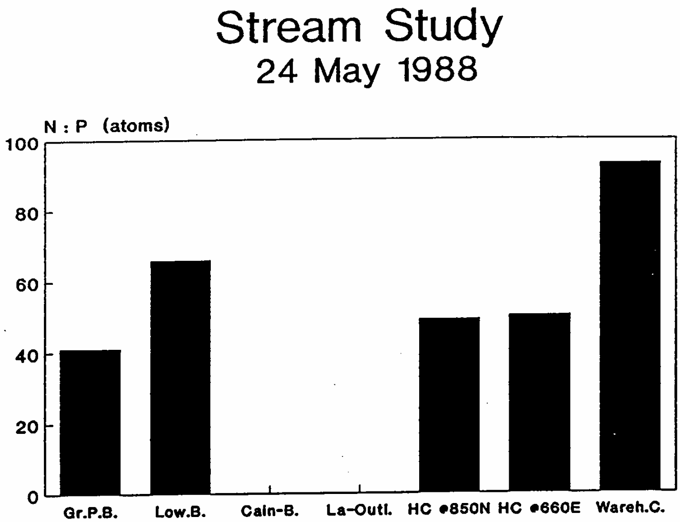


Figure 44. Ortho Phosphorus Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



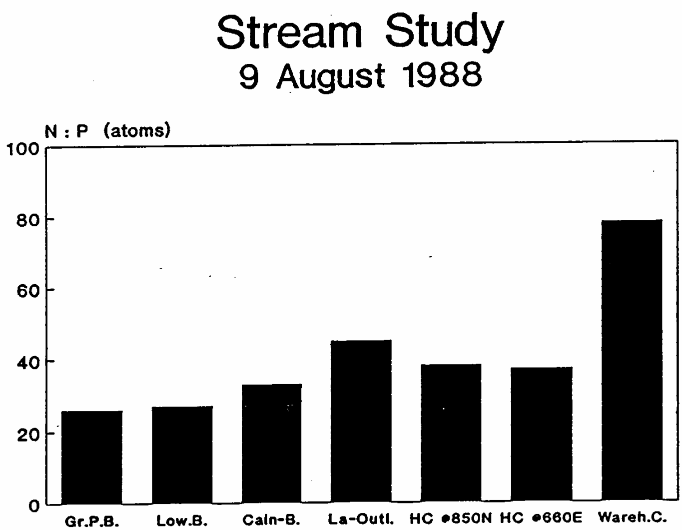
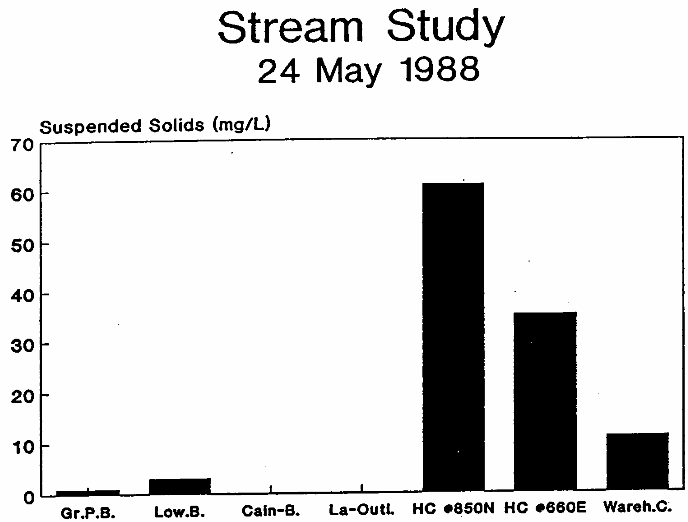


Figure 45. Nitrogen to Phosphorus Ratios in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.



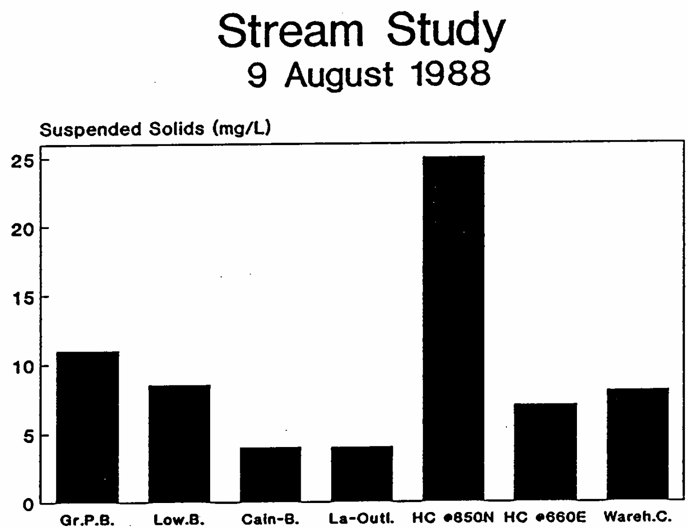


Figure 46. Total Suspended Solids in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La-Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During May and August 1988.

phytoplankton biomass. TSS values decreased for stream stations between May and August reflecting lower flow conditions and watershed stabilization by growing crops, but values for this parameter increased at all lake stations during the same period reflecting normal summertime buildup of algal biomass in the water column.

Chlorophyll was measured only during August (Figure 47). At that time chlorophyll was maximal at both sites in Henderson Lake Ditch with the 850 N site being greater than the 660 E site. The rank ordering of the Henderson Lake Ditch sites is rather interesting given that the 850 N site had lower concentrations for all phosphorus and nitrogen forms except nitrate. As for chlorophyll, pheophytin was greater at the Henderson Lake Ditch sites but the rank ordering of these sites was opposite of that shown for chlorophyll (Figure 48). Regarding lake stations, the individual sites were ranked in order of decreasing chlorophyll as lake outlet, Cain, Gravel Pit, and Lower basins. All lake sites were clearly eutrophic.

Microbiology

Microbiological samples were collected only on 9 August 1988. All stream and lake stations were sampled. Details on sampling methodology were not provided to the author by Turnbell Engineering. Fecal coliform bacteria were greatest at the lake outlet (6220 mpn/mL) followed by Henderson Lake Ditch at 850 N (910 mpn/mL) and Waterhouse Ditch (500 mpn/mL) (Figure 49). All three sites exceeded the state standard of 400 mpn/mL for total fecal coliform bacteria.

Fecal streptococcus were greatest in Waterhouse Ditch (160 mpn/mL) followed by the two sites on Henderson Lake Ditch and the lake, with the latter three sites having 84-88 mpn/mL (Figure 50). Only the Waterhouse Ditch site exceeded the state standard of 100 mpn/mL for this parameter. Within the lake fecal streptococcus values were greatest in Gravel Pit basin and the outlet. The FC:FS ratio is often used to separate the contribution of animal versus human sources. The greatest FC:FS ratio of any sites sampled were found at the lake outlet followed by Lower basin and Henderson Lake Ditch at 850 N (Figure 51) but the data were not sufficient to separate human from warm-blooded animal fecal contamination.

Five-day Biochemical Oxygen Demand (BOD) was run on lake and stream station during both May and August 1988 (Figure 52). The highest BOD value for any stream station during May was from the 850 N site of Henderson Lake Ditch followed by the 660 E site of the same ditch. During both May and August Lower basin exceeded Gravel Pit basin, and both were greater than Waterhouse Ditch. During August all lake stations exceeded stream stations for this parameter.

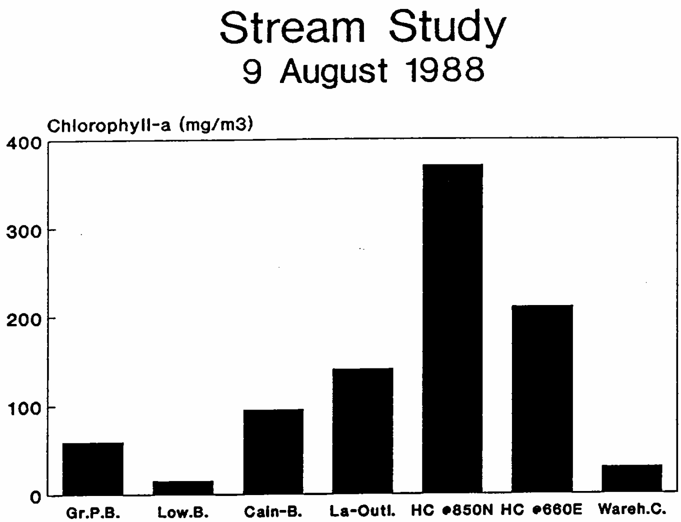


Figure 47. Chlorophyll A Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.

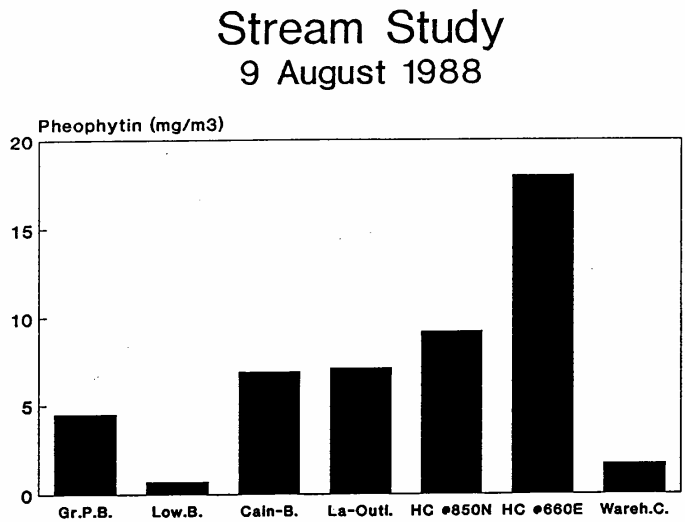


Figure 48. Pheophytin Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.

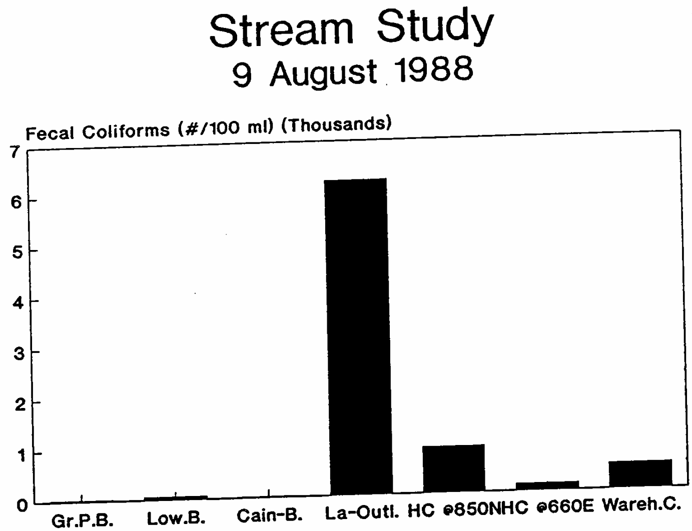


Figure 49. Fecal Coliform Bacteria Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.

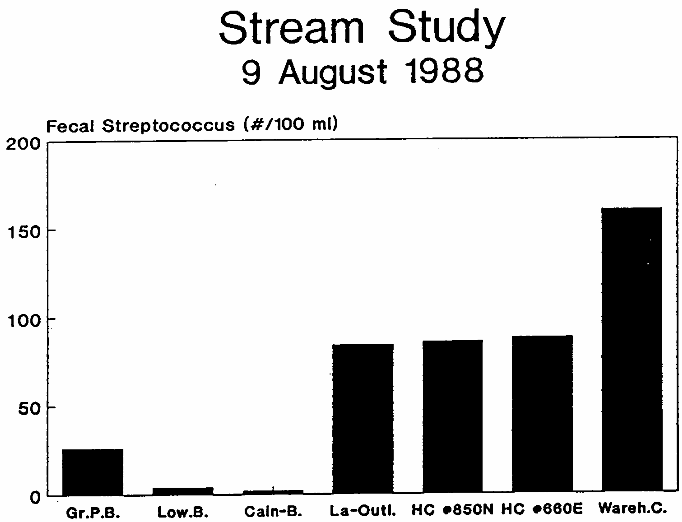


Figure 50. Fecal Streptococcus Concentrations in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La -Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.

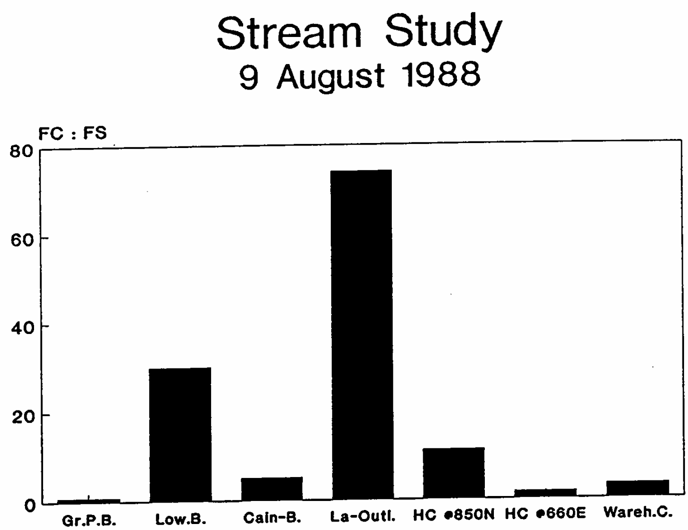
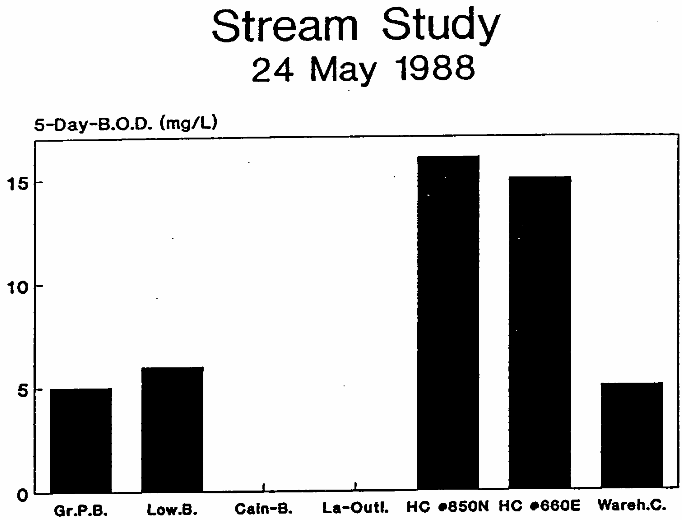


Figure 51. Fecal Coliform to Fecal Streptococcus Ratios in Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La-Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.



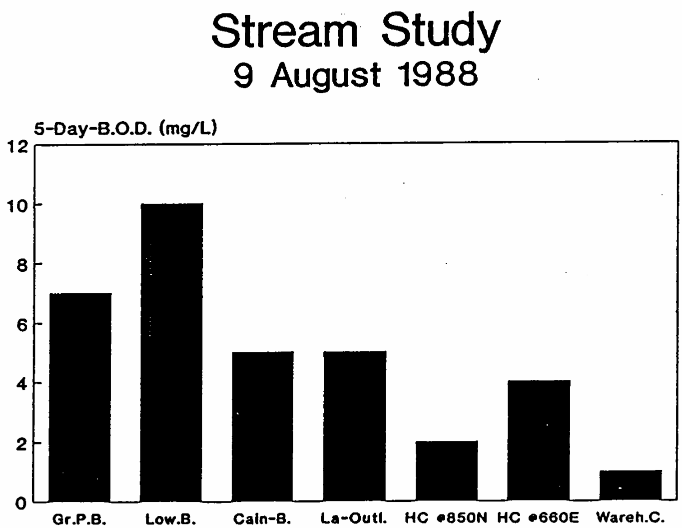


Figure 52. Five Day BOD Values for Gravel Pit (Gr.P.B.), Cain (Cain B.) and Lower (Low.B) Basins of Sylvan Lake, the Lake Outlet (La-Outl.), two stations of Henderson Lake Ditch (HC) and Waterhouse Ditch (Wareh.C.) During August 1988.

Such data are extremely spotty and are of limited value except to note trends in BOD.

One can not conclude a great deal from the microbiological testing for Sylvan Lake and watershed. Although some bacterial contamination was noted in 1988, additional testing would have to be performed in order to make any definitive statements as its severity during a "normal" year.

Macrophytes

No data on the species composition and aerial extent of aquatic macrophytes during 1988 were provided. I assume that the information provided from the DNR survey of 1987 applied to 1988 (Table 6).

Watershed Investigation

As mentioned earlier, two principal streams flow into Sylvan Lake system: Henderson Lake Ditch which receives the drainage of Waterhouse Ditch and Oviatt Ditch. Details of each subsection of the Sylvan Lake watershed were provided earlier in this report. The United States Environmental Protection Agency calculated that in 1973 Henderson Lake Ditch alone contributed 79% of the total phosphorus loading to Sylvan Lake alone. Of this total, the Kendallville sewage treatment plant contributed 41% of total lake loading. Oviatt Ditch contributed only 11% and Latta Lake outlet 2%.

Turnbell Engineering estimated phosphorus loading to Sylvan Lake from a Reckhow and Simpson (1980) lake phosphorus model. Calculations and assumptions of this model are included in Appendix A. Model calculations estimated that Waterhouse Ditch contributed 16% of total phosphorus loading to Sylvan Lake during 1988, and when combined with Henderson Lake Ditch contributed 66% of total loading (Table 14). Henderson Lake and the Kendallville sewage treatment plant contributed 23% of loading or 35% of the total contribution from the Henderson Lake Ditch - Waterhouse Ditch segment of the watershed. While the rank ordering of phosphorus sources remained the same between 1973 and 1988 calculations, the latter results should be viewed as only preliminary given the limited ground truth data entered for 1988 and the unusual temperature and drought conditions of that year.

The estimated contribution to total phosphorus loading by individual land use categories is provided in Table 15. Rowcrops appear to be contributing approximately 53% of total loading with an additional 37% being contributed by internal lake sources. The Kendallville sewage treatment plant was third at 6%. Of the three principal sources, the Kendallville STP should be the easiest to control.

The contribution of the Kendallville STP can be expected to change markedly temporally associated with periodic sewage bypass events. As an example of the severity of the problem, a total of 37 bypass events were reported for the period March-December 1988 (Table 16). Such events can markedly increase the contribution of the STP to total phosphorus loading for Sylvan Lake. Assessment of the full contribution from this source is beyond the scope of this report.

Two additional watershed problems that could adversely affect Sylvan Lake were noted by Turnbell Engineering. At least four illegal dumps are in close proximity to Sylvan Lake, with one being directly on the lake shore (Figures 53 and 54). At the time of the Turnbell investigation in 1988,

Table 14. Sylvan Lake Phosphorus Loadings by Subbasin.

Subbasin	Phosphorus Loading (kg/yr)
1 - Latta Lake	526
2 - Sylvan Lake	4603
3 - Oviatt Ditch	1349
4 - Latta Lake Creek	7
5 - Unnamed	15
6 - Henderson Ditch	816
7 - Little Long Lake	185
8 - Henderson Lake	1281
9 - Round Lake	493
10 - Bixler Lake	756
11 - Waterhouse Ditch	255

	10,287 kg/yr

Table 15. Phosphorus Loadings to Sylvan Lake According to Land Use Category.

	High	Most Likely	Low
Forest land	73	36	7.3
Rowcrop land	21785	5446	549
Pastures	3561	119	59
Urban	2210	265	88
Wetlands	17	-87.0	-435
Precip	81	54	27
Internal	4614	3845	923
Kendallville STP	1218	609	152
TOTAL kg/yr	33,559	10,287	1,366

Table 16. Recorded Overflow Bypass Events at the Kendallville Sewage Treatment Plant for the Period March-December 1988.

Date	B.O.D. (mg/L)	Susp. sol (mg/L)	ph	PO4 (mg/L)	Ammonia (mg/L)	Fecal (#/100ml)	Flow (MGD)
3/23	267.	2290	7.37	4.05	4.10	---	0.181
3/24	77.	152	7.48	1.85	4.81	---	1.604
3/25	118.	92	7.27	3.08	---	---	0.333
3/30	10.	36	7.44	.90	---	---	0.025
4/3	117.	924	6.46	2.64	2.33	1,900,000	0.115
4/6	67.	62	7.56	2.03	3.11	1,890,000	0.750
4/7	109.	26	7.61	1.72	---	1,010,000	0.102
5/23	68.	472	6.93	---	4.48	---	0.157
5/24	30.	76	7.25	---	1.71	---	0.173
6/15	146.	556	6.79	4.40	3.12	552,000	0.142
7/14	146.	572	6.82	4.09	6.01	---	0.141
7/18	---	---	---	---	---	---	0.494
7/22	106.	328	7.66	3.50	6.90	---	0.652
7/25	55.	224	7.64	2.65	2.05	---	0.203
7/30	94.	892	7.49	2.40	---	---	0.354
8/3	159.	156	8.29	5.20	20.3	---	0.006
8/5	149	224	8.04	2.30	5.63	---	0.002
8/10	157.	300	7.52	2.56	2.55	---	0.542
8/15	118.	304	7.68	2.15	3.88	---	0.304
8/18	102.	152	7.75	1.90	4.20	---	0.387
8/23	209.	584	7.85	4.15	14.4	---	0.145
8/27	---	---	---	---	---	---	0.072
9/3	46	152	7.60	---	---	---	0.017
9/19	113	136	7.52	2.83	4.07	---	0.021
10/17	41	372	7.96	1.68	2.79	---	0.050
10/18	26	700	7.80	3.00	1.68	---	0.038
11/9	80	450	7.78	1.85	2.70	82,800	0.027
11/10	50	236	7.64	1.68	2.25	78,600	0.112
11/16	46	40	7.64	0.26	2.88	46,000	0.206
11/17	51	36	7.95	2.00	5.12	920,000	0.036
11/20	78	128	7.63	1.45	4.00	280,000	0.122
12/20	401	1130	7.04	4.81	3.88	820,000	0.001
12/22	---	---	---	---	---	---	0.081
12/23	106	452	7.42	6.33	2.79	620,000	0.023
12/27	87	74	7.31	1.82	3.41	5,100	0.092

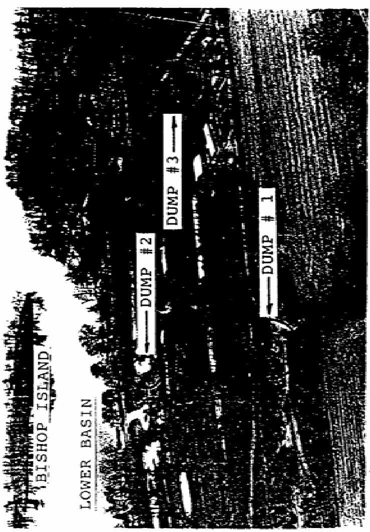
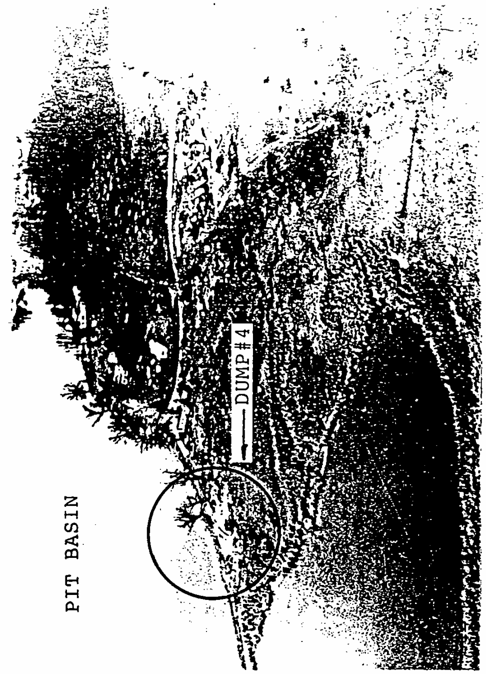
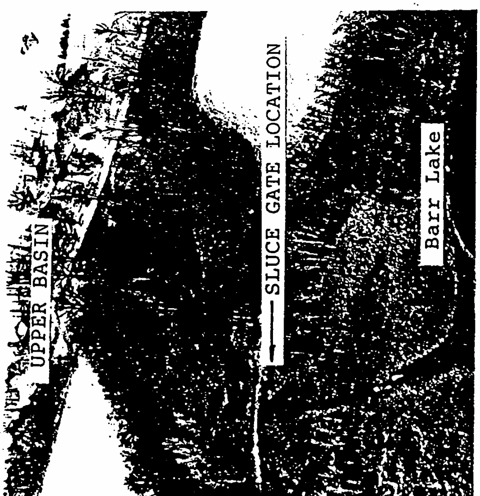


Figure 53.

Illegal Dump Sites in the Sylvan Lake Watershed.





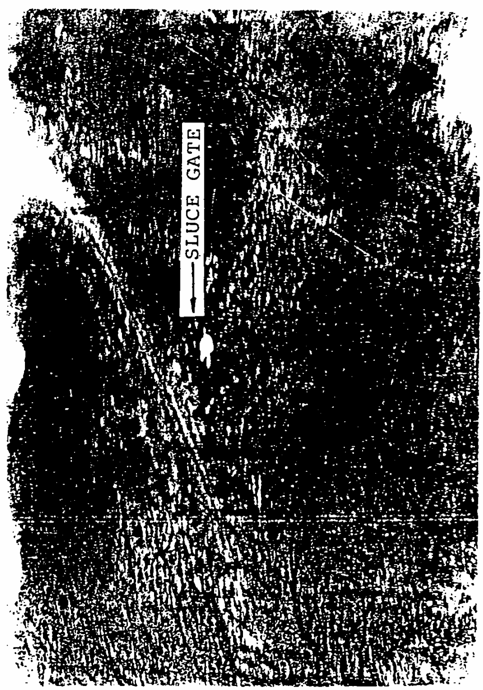


Figure 54.

Illegal Dump Sites in the Sylvan Lake Watershed and Flow Constriction Between Barr Lake and Sylvan Lake.

state agencies were informed of the dumps and issued letters to the offending parties to clean the areas. Apparently, this was not done. Turnbell reported that construction debris is the prime contributor to such dumps, but paint cans, food and petroleum product containers and general household refuse was also observed. Finally, flow to Sylvan Lake from Barr Lake has been restricted by simple sluice gate in the oulet from Barr Lake (Figure 54). Residents complained of periodic discharge of "stagnant" water from Barr Lake into Sylvan Lake. Detailed examination of either of the above issues were not undertaken as part of the Turnbell Engineering investigation of Sylvan Lake.

Finally, as wetlands have been shown nationally to have important wildlife and water mitigation attributes, it is essential to have an inventory of the extent of wetlands in the Sylvan Lake watershed. The largest wetland areas of the watershed are located along the south shore of Bixler Lake, at the eastern end of Gravel Pit Basin of Sylvan Lake and in the vicinity of Needham Lake northeast of Sylvan Lake. The Bixler Lake wetland nature area consists of 75 acres of woods, marsh and field habitats and is managed to encourage wildlife populations. A marked trail and observation platforms facilitate observation of wildfowl.

The wetlands east of Sylvan Lake are currently undisturbed, and the area receives all major inlet drainage to the lake. The wetlands on the eastern edge of Needham Lake is known as the Needham Lake (or Swamp Angel) Nature Preserve. This wetland habitat comprises 95 acres and is diverse area with a small lake and a large high quality fen. This nature preserve is part of an even larger wetland area covering approximately 250 acres. Finally, three additional areas are located in the immediate vicinity of Sylvan Lake. In addition to a registered wetland between Boy Scout Island and the eastern shore of Sylvan Lake, two additional sites are located along the southern shore of the Lower Basin west of Kerr Island bridge and approximately 3/8 miles south of Rome City on the west side of Kelley Street.

Conclusions and Recommendations

Water quality in Sylvan Lake began to deteriorate early in this century. By the early 1930's, macrophyte growth was considered excessive and winter kills of fish were common. During this period, it was established that the principal source of the lake's problems was sewage from Kendallville entering Henderson Lake and ultimately Sylvan Lake. The town was mandated to build a sewage treatment plant.

Cultural eutrophication continued through the next decades so that by the early 1960's local residents decided to initiate a chemical control program for macrophytes. Between 1962 and 1968, over 30 tons of copper sulphate were used in this effort. This control program was overly effective and led to even more pronounced algal blooms as nutrients were no longer being taken up by rooted vegetation. As vegetation was being reduced in the lake, the habitat opened for carp, which in turn, stirred bottom sediments likely promoting nutrient recycling and increased turbidity that interferred with largemouth bass populations. Through overally zealous mismanagement, the lake problem had shifted from macrophytes to phytoplankton.

Phosphorus concentrations in the lake declined markedly in the early 1970's as the Kendallville sewage treatment plant was updated to control phosphorus emissions and a state wide ban was imposed on detergent phosphorus. In spite of such reduction in loading, the lake continued to be algal-carp dominated. During the latter half of the 1970's, a series of winter drawdowns were undertaken for the purpose of consolidating shallow water sediments and associated reduction of nutrient recycling. Unfortunately, the remaining submergent macrophytes of the lake, which were restricted to shallow near shore areas, were destroyed by such a management practice making phytoplankton domination complete. The lake drawdowns did not reduce phosphorus concentrations in the lake nor was there a marked improvement in the recreational fishery. In fact, populations of several taxa of rough fish seemed to be stimulated by lake drawdowns.

A chemical fish eradication program was undertaken in 1984 and followed up by a series of restockings from 1984 through 1987. The impact of this program on water quality in Sylvan Lake has been dramatic. Carp were all but eliminated in the lake and as a result water clarity has increased progressively since 1984. The end result has been a reestablishment of submergent macrophytes and a progressive increase in the depth to which they are able to grow. In fact, in recent DNR surveys, macrophyte growth in some near shore areas is considered to be causing some slight management problems. Most interesting is the fact that such improvement in perceived water quality have taken place even though phosphorus concentrations have remained unchanged throughout the period.

From the investigation conducted by Turnbell Engineering, it is extremely difficult for me to make sound management recommendations for the lake basins. This is true regarding both watershed and lake management. No data were provided on macrophyte species composition, aerial extent of growth, and depth distribution of biomass. Without knowing such details of the problem, a long term management solution can not be formulated. No data were provided on the extent of basin infilling and whether such infilling was serious enough to warrant sediment removal or similar management options. In order to address this important question, it is recommended that a new bottom map be made for Sylvan Lake for comparison with those of 1927 and 1976 in order to estimate both the extent of basin infilling and potential costs for its management. Sampling for 1988 was extremely spotty, and because of temperature and drought conditions, may not be representative of current conditions.

The Turnbell Engineering watershed modelling effort was marginal at best. Given the extreme size of the watershed, it is recommended that detailed ground truth data be collected for inclusion into a watershed model. A more complete assessment of the contribution of the Kendallville sewage treatment plant ~~is needed~~ including the problem of sewage bypass. The available data suggest that even if the Kendallville plant is operating at peak efficiency, there is sufficient phosphorus and nitrogen stored in the sediments of Henderson Lake to be an extremely important nutrient loader to Sylvan Lake for the distant future. Any watershed management plan must address ways of reducing the loading from Henderson Lake sediments.

Given that large segments of the Sylvan Lake watershed drain into a suite of lakes prior to entering Sylvan Lake proper, I suggest including a brief survey of each of these lakes as part of the next phase of study at Sylvan Lake. This should be an easy way to see which segments of the watershed are in need of detailed land use examination. As noted for Henderson Lake, it is important to know if the sediments of individual small lakes are a source of nutrient loading downstream for Sylvan Lake. Even with improved watershed management practices, sediments will continue to release nutrients for years to come.

In addition to reducing Henderson Lake nutrient release from sediments, I feel that construction of a wetland at the eastern end of Gravel Pit basin that will represent an expansion of the present wetland would drastically reduce nutrient loading to Sylvan Lake. Initial examination indicates such an option should be able to be done in an extremely cost effective manner. Given the short residence time of Sylvan Lake (six months), reduction of nutrient loading from streams entering the lake at the eastern end of Gravel Pit basin, should result in minimal lag time between construction and improvement in water quality. Several additional wetlands are present in the Sylvan Lake watershed that could possibly be expanded upon as part of any plan to reduce watershed release of nutrients. In any event, the current wetlands of the Sylvan Lake watershed should be left intact in order to facilitate their role in nutrient retention and wildlife preservation.

According to the local SCS office, approximately 40% of agricultural land in the Sylvan Lake watershed is currently under some form of soil conservation measure. Such measures include pasture land-hay field rotation on dairy farms, conservation tillage practices and a 10 year commitment to put land in grass or trees. There have been no "T by 2000" structural applications made for any watershed segment. Given that at least 85% of soils of the watershed require management to prevent erosion and the fact that 53% of phosphorus loading to the lake comes from rowcrops, it is essential that current management practices be supplemented and applied to additional large areas of the watershed. Additional methods for structural (diversions, grass waterways) and cultural (reduced tillage) land treatment practices must be examined to reduce erosion within the watershed. Finally, attention should be paid to elimination of illegal dumps sites within the watershed given that such sites could be potential sources of contaminants to Sylvan Lake.

I feel that we have a sufficient picture of Sylvan Lake to warrant development of a design phase application. It is my recommendation that sites be located for wetland construction near the mouth of Henderson Lake Ditch and detailed plans be drafted. Phase II should include detailed watershed modelling including the impact of watershed management on lake water quality. Given the inadequacy of the current database, detailed examimation of both the macrophytes and basin infilling must be considered an integral part of the design phase work. Without such information a cost effective long term management plan for both the lake and its watershed can not be formulated.

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APPENDIX A

PHOSPHORUS COMPUTER MODELING
(Harza, 1989)

The lake phosphorus model employed for this study uses export coefficients derived from other studies, since financial constraints prohibit "T by 2000" projects from conducting "in situ" studies. Ken Reckhow and others compiled and screened export coefficients according to certain statistical and substantive criteria in their publication "Modeling Phosphorus Loading and Lake Response Under Uncertainty: a Manual and Compilation of Export Coefficients," (Reckhow. et al, 1980) This compilation provides the researches' measured export coefficients for various watershed according to: climate, location, land use, soil type, vegetative cover, and other criteria.

Based on these descriptions, export coefficients were selected for use in the model, according to the information available on the lakes' subbasins from land use maps and field reconnaissance. For the sake of practicality, high, most likely, and low export coefficients were selected. This allows calculation of high, most likely, and low phosphorus loading estimates, which represent the uncertainty of the loading estimates. The high and low estimates represent additional error that is incremental to the model error, and must be included in the calculation of total uncertainty. In other words, the range between the high and low export coefficients reflects the uncertainty inherent in extrapolating the information from Reckhow's compilation to the project areas.

Following is a printout of the phosphorus computer modeling:

LAKE PHOSPHORUS MODEL
(Based upon Reckhow and Simpson, 1980)

$P = L/(11.6 + 1.2 * qs)$

Where: P = Lake phosphorus concentration (mg/L)
L = Phosphorus loading (g/sq m-yr)
qs = Areal water loading (m/yr)

Estimation of qs for Sylvan Lake:

$Q = (Ad * r) + (Ao * Pr)$

and

$qs = Q/Ao$

Where: Q = Inflow water volume (cu m/yr)
Ao = Lake surface area = 2,707,000 sq m
Ad = Watershed area = 87,519,600 sq m
r = Total annual unit runoff = 0.3 m/yr
Pr = Mean annual net precipitation = 0.87 m/yr

Q =2.86E+07 cu m/yr
qs = 10.57 m/yr

Estimation of L for Sylvan Lake

$M = (Ef * Af) + (Ea * Aa) + (Eg * Ag) + (Eu * Au) + (Ew * Aw) + (Ep * Ao) + (Ei * Ai) + PSI$

and

$L = M / Ao$

Where: M = Total phosphorus mass loading (kg/yr)
Ef = P export coefficient for forest land (kg/ha-yr)
Af = Area of forest land (ha)
Ea = P export coefficient for rowcrop land (kg/ha-yr)
Aa = Area of rowcrop land (ha)
Eg = P export coefficient for pasture (kg/ha-yr)
Ag = Area of pasture (ha)
Eu = P export coefficient for urban land (kg/ha-yr)
Au = Area of urban land (ha)
Ew = P export coefficient for wetland (kg/ha-yr)
Aw = Area of wetland (ha)
Ep = P export coefficient for precipitation (kg/ha-yr)
Ei = P export coefficient for hypolimnion (kg/ha-yr)
Ai = Area of lake anoxia (ha)
PSI = Point source inputs (kg/yr)

		Phosphorus Export Coefficients		
Sources	Area	High	Most Likely	Low
Forest	365 ha	0.2	0.1	0.02 kg/ha-yr
Rowcrop	5446	4.0	1.0	0.1
Pasture	1187	3.0	0.1	0.05
Urban	884	2.5	0.3	0.1
Wetland	870	0.02	-0.1	-0.5
Precip	271	0.3	0.2	0.1
Internal	154	30	25	6
PSI		200%	100%	25%

November 2, 1988

Sylvan Lake Phosphorus Model

	Phosphorus Mass Loading			
	High	Most Likely	Low	
Forest	73	36	7.3	kg/yr
Rowcrop	21785	5446	545	
Pasture	3561	119	59	
Urban	2210	265	88	
Wetland	17	-87.0	-435	
Precip	81	54	27	
Internal	4614	3845	923	
PSI	1218	609	152	
W =	33,559	10,287	1,366	kg/yr

Areal phosphorus loading (L):

High = 12.4 g/sq m/yr
Most likely = 3.8
Low = 0.50

Calculation of P (Lake Phosphorus Concentration):

High = 0.511 mg/L
Most likely = 0.157
Low = 0.021

ESTIMATION OF UNCERTAINTY (St)

log P (most likely) = -0.805

"Positive" model error = 0.0536 mg/L

"Negative" model error = -0.0399 mg/L

"Positive" loading error = 0.1770 mg/L

"Negative" loading error = 0.0679 mg/L

"Positive" uncertainty = 0.1850 mg/L

"Negative" uncertainty = 0.0787 mg/L

55% confidence limits (lower) = 0.078 mg/L
55% confidence limits (upper) = 0.341 mg/L

90% confidence limits (lower) = -0.0010 mg/L
90% confidence limits (upper) = 0.526 mg/L

PHOSPHORUS LOADINGS BY SOURCE

Watershed 1: Latta Lake

Source	Area (ha)	High	Likely	Low	
Forest	4	1	0	0	kg/yr
Rowcrop	525	2100	525	53	
Pasture	105	316	11	5	
Urban	0	0	0	0	
Wetland	102	2	-10	-51	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	736	2419	526	7	

Watershed 2: Sylvan Lake

Source	Area (ha)	High	Likely	Low	
Forest	42	8	4	1	kg/yr
Rowcrop	686	2745	686	69	
Pasture	136	407	14	7	
Urban	75	187	22	7	
Wetland	220	4	-22	-110	
Precip	271	81	54	27	
Internal	154	4614	3845	923	
PSI		0	0	0	
	1583	8046	4603	924	

Watershed 3: Oviatt Ditch

Source	Area (ha)	High	Likely	Low	
Forest	111	22	11	2	kg/yr
Rowcrop	1335	5339	1335	133	
Pasture	131	393	13	7	
Urban	4	10	1	0	
Wetland	111	2	-11	-56	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	1692	5767	1349	87	

Watershed 4: Latta Lake Creek

Source	Area (ha)	High	Likely	Low	
Forest	0	0	0	0	kg/yr
Rowcrop	6	24	6	1	
Pasture	9	27	1	0	
Urban	0	0	0	0	
Wetland	1	0	-0	-1	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	16	52	7	1	

November 2, 1988

Sylvan Lake Phosphorus Model

Watershed 5: Unnamed

Source	Area (ha)	High	Likely	Low	
Forest	0	0	0	0	kg/yr
Rowcrop	15	62	15	2	
Pasture	6	19	1	0	
Urban	0	0	0	0	
Wetland	12	0	-1	-6	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	34	81	15	-4	

Watershed 6: Henderson Ditch

Source	Area (ha)	High	Likely	Low	
Forest	46	9	5	1	kg/yr
Rowcrop	790	3161	790	79	
Pasture	208	625	21	10	
Urban	27	68	8	3	
Wetland	76	2	-8	-38	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI	0	0	0	0	
	1147	3866	816	55	

Watershed 7: Little Long Lake

Source	Area (ha)	High	Likely	Low	
Forest	4	1	0	0	kg/yr
Rowcrop	173	690	173	17	
Pasture	0	0	0	0	
Urban	57	142	17	6	
Wetland	47	1	-5	-23	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	280	834	185	-0	

Watershed 8: Henderson Lake

Source	Area (ha)	High	Likely	Low	
Forest	36	7	4	1	kg/yr
Rowcrop	561	2244	561	56	
Pasture	145	434	14	7	
Urban	319	797	96	32	
Wetland	25	1	-3	-13	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		1218	609	152	
	1087	4702	1281	235	

November 2, 1988

Sylvan Lake Phosphorus Model

Watershed 9: Round Lake

Source	Area (ha)	High	Likely	Low	
Forest	75	15	7	1	kg/yr
Rowcrop	451	1803	451	45	
Pasture	190	569	19	9	
Urban	82	206	25	8	
Wetland	90	2	-9	-45	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	888	2595	493	19	

Watershed 10: Bixler Lake

Source	Area (ha)	High	Likely	Low	
Forest	34	7	3	1	kg/yr
Rowcrop	665	2660	665	67	
Pasture	193	580	19	10	
Urban	281	702	84	28	
Wetland	158	3	-16	-79	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	1331	3952	756	26	

Watershed 11: Waterhouse Ditch

Source	Area (ha)	High	Likely	Low	
Forest	12	2	1	0	kg/yr
Rowcrop	239	956	239	24	
Pasture	63	190	6	3	
Urban	39	97	12	4	
Wetland	29	1	-3	-15	
Precip	0	0	0	0	
Internal	0	0	0	0	
PSI		0	0	0	
	383	1247	255	17	
		33,559	10,287	1,366	kg/yr